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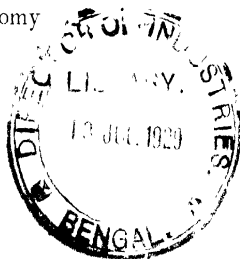
Finding and Stopping Waste
in Modern Boiler Rooms

$\beta - 166$

A Reference Manual to Aid the
Owner, Manager and Operator
in Securing and Maintaining
Boiler Plant Economy

Price, $3.00

Third Edition, Revised and Enlarged

"Exact knowledge rests upon measurements"

COCHRANE CORPORATION

PHILADELPHIA : PENNSYLVANIA

Contents

Section I—FUELS

Section II—COMBUSTION

Section III—HEAT ABSORPTION

Section IV—BOILER EFFICIENCY AND TESTING

Section V—FEED WATER HEATING AND CONDITIONING

COCHRANE CORPORATION

PREFACE TO FIRST EDITION

The subject matter of this hand book, originally intended as an appendix to o
Catalog of Cochrane V-Notch Meters, has grown to require a separate volume   T
information has been selected with a view to its service to owners, managers, en;
neers and firemen in increasing and maintaining boiler plant economy.   We ha
preferred such statements, tables, charts, etc, as were supported by experiments ai
tests, and, wherever possible, have given references to the original authority

In view, however, of the great range and diversity of the subjects necessari
comprised in a treatment of boiler-plant economy, it has obviously been impracticab
to test every statement by experience, but considerable pains have been taken to che
each authority against others   Mi Henry Kreisinger, who conducted for the Unit(
States Bureau of Mines many of the steam boiler investigations mentioned in the f(
lowing pages, also has kindly read the proof sheets

Using such information as is here presented, the user of a Cochrane Meter
Metering Heater is enabled to increase the economy of his plant by trying one by oi
the effects of changes in fuels and of improvements in methods and equipment.   Ha
ing determined from the indications of the Meter which fuels, methods and arrang
ments are best, they can be standardized, and the Meter will thereafter show wheth
or not these maximum possibilities are being realized in daily practice

HARRISON SAFETY BOILER WORKS

August 3, 1917.

PREFACE TO THIRD EDITION

Advantage has been taken of the necessity of resetting this book to revise tl
original text and to introduce new matter, particularly in connection with heat balan
ing and the preparation and heating of boiler feed water

July 1, 1927.   COCHRANE CORPORATION.

Section I—Fuels

CLASSIFICATION OF COALS

Wood fibre or cellulose is the lowest group in a carboniferous series, including peat, lignite, bituminous coal, semi-bituminous coal, semi-anthracite, anthracite and graphite. The lower groups are low in carbon and high in oxygen. Each succeeding group is distinguished by an increase in carbon and a decrease in oxygen. The hydrogen remains practically the same for all groups below the semi-bituminous, but decreases rapidly in the higher groups. It is difficult to define each group exactly. One method is according to the percentage of volatile matter, as in the table below, from *Steam.*

Name	% Fixed Carbon	% Volatile	BTU per lb. Combustible
Anthracite	97 to 92.5	3 to 7.5	14600 to 14800
Semi-anthracite	92.5 to 87.5	7.5 to 12 5	14700 to 15500
Semi-bituminous	87.5 to 75	12.5 to 25	15500 to 16000
Bituminous Eastern	75 to 60	25 to 40	14800 to 15300
Bituminous Western	65 to 50	35 to 50	13500 to 14800
Lignite	Under 50	Over 50	11000 to 13500

The above figures are on a "moisture free" basis. The moisture in lignites may be as much as 45% or 50%, reducing the *BTU* per lb. "as received" accordingly.

M. R. Campbell has suggested a classification based upon the carbon-hydrogen ratio. Carbon and hydrogen are both valuable fuel elements, hence both should be taken into account. *Cosgrove* divides coal into twelve groups, as given in the table below. The bituminous coals are divided into four groups, where ordinarily there is no distinction made, the low-grade fuels of the Mississippi Valley being separated in his classification from the high-class coals of the Appalachian region.

Class	Group	Ratio C/H
Anthracite	A	Over 30
Anthracite	B	30 —28
Anthracite	C	28 —26
Semi-anthracite	D	26 —23
Semi-bituminous	E	23 —20
Bituminous	F	20 —17
Bituminous	G	17 —14 4
Bituminous	H	14 4—12.5
Bituminous	I	12.5—11.2
Lignite	J	11.2— 9.3
Peat	K	9.3
Wood	L	7.2

The proposed *A.S.M.E. Test Code* cites the *Frazer* classification as a rough indication of how coal should be burned, and what results may be expected:

	Volatile, %	Vein moisture, %
Anthracites	Below 5	
Semi-anthracites	5-10	
Semi-bituminous	15-22	
Eastern bituminous	25-35	2-4
Mid-Continental bituminous	35-45	
Black lignites or sub-bituminous.	35-40	17-20
Brown lignites	25-45	20-25

The following characterizations of different coals are due to the *U. S. Geological Survey, Steam* and *Cosgrove:*

Graphite is not available for fuel, because of the high temperature required for its ignition.

Anthracite, commonly known as **hard coal,** is practically all fixed carbon. It has a deep black color, a shiny, semi-metallic luster, few joints and clefts, and is compact and sometimes iridescent. The specific gravity ranges from 1.3 to 1.8. Anthracite neither softens nor swells when burning. It kindles slowly and with difficulty and burns with a short, yellowish flame, which changes to a faint blue and is transparent in appearance, owing to the absence of particles of solid carbon.

Semi-anthracite is not as hard or dense, and does not have the luster of true anthracite. It can be distinguished by the fact that when newly fractured it will soot the hand. The specific gravity is about 1.4. Semi-anthracite contains more gaseous matter, and for that reason kindles more readily and burns more rapidly than the true anthracite. It makes a very intense, free-burning fire.

Semi-bituminous coal is still softer than the semi-anthracite, and lacks most of the bright metallic luster, although it is brighter in appearance than bituminous coal. It contains more volatile hydrocarbon, kindles more easily and burns more rapidly than the anthracite, but resembles anthracite more than it does bituminous coal. It is ordinarily free-burning, without smoke, and has a high calorific value. It is of the highest class for steam generating purposes.

Bituminous coals are commonly called **soft coals.** They consist of fixed carbon and bitumen. This is a mixture of hydrocarbons, which, when heated, breaks down into gases, oils and tars. Bituminous coals have more volatile matter than the preceding classes. The range in specific gravity is from 1.25 to 1.4, and the color from dark brown to pitch black. In hardness they range from lignite to semi-bituminous. The harder varieties have the best heating values. Generally bituminous coals are brittle, with a vitreous, resinous or greasy luster. The distinction between semi-bituminous and bituminous coals is important economically, for the semi-bituminous have about 6% higher heating value per lb. of combustible, and burn with much less smoke. Bituminous coals absorb moisture from the atmosphere. The surface moisture will dry out naturally, but the moisture absorbed internally is driven out only at a temperature of 250° F. A distinguishing characteristic is a yellow flame and smoke when burning. There are two types of bituminous coals, designated generally as caking

coals, and non-caking or free-burning coals. Caking coals are very rich in hydrocarbons, and valuable therefore in gas manufacture. They fuse and swell when heated. Non-caking coals do not fuse, but hold their shape, burn much more freely, and are preferable for steam purposes.

Sub-bituminous coal is frequently called black lignite, and is not readily distinguishable from either lignite or bituminous coals. Its chief characteristic is its tendency to absorb moisture if exposed to the weather, and to slake like lime. It has a fairly bright luster.

Lignite is sometimes called brown coal, and is vegetable matter in the early stages of coal formation. The specific gravity ranges from 1.2 to 1.23. When first mined, it may contain up to 50% of moisture. The color is light brown, showing a distinct woody structure in the poorer varieties, ranging to black with a pitchy luster resembling hard coal in the best varieties. It is non-caking, and burns with a slightly smoky flame, with moderate heat. It is easily broken, and will not stand handling in transportation. The ash content of lignite ranges from 1 to 50%. It is distinctly a low-grade fuel, but cheap. Analyses of typical lignites will be found under "North Dakota" and "Texas" in the table on page 20.

Peat is organic matter in the first stages of conversion to coal. It is found in bogs. It contains 75 to 95% of moisture when dredged and retains 15 to 20%, or even 30%, when air dried. If dried artificially beyond this point it must be used immediately or briquetted with a waterproof binder, as otherwise it will reabsorb water. When air dried it contains about 7,500 *BTU* per lb. Large deposits are found in this country, but as yet are little used. The *Canadian Department of Mines* reports a test of peat used as fuel under B. & W. water-tube boilers in which an equivalent evaporation of 3 to 4 lb. of water per lb. of fuel as fired was obtained, the peat containing 16 to 20% moisture and 7,600 to 8,100 *BTU*. The boiler efficiency averaged 50%.

Coke is the somewhat porous material remaining after the volatile constituents of coal have been driven off by slow heating. It consists almost entirely of fixed carbon and ash, and has an average heating value of 14,300 *BTU* per lb. Coke from gas ovens is less compact and is easier to ignite than is metallurgical coke.

PRINCIPLE OF TRILINEAR COORDI-NATES USED IN PLOTTING COAL ANALYSES POINT P REPRESENTS THE COMPOUND $C_6H_{10}O_5$, CONTAINING BY WEIGHT 44.4%C, 6.2%H, 49.4%O.

The classification and nomenclature of coals on a scientific basis are desirable, but do not always agree with classifications based on the behavior of coals in practical use. *O. C. Rolston* presents a graphic study of coal, based on trilinear coordinates, as shown in the above chart.

The coal analysis is computed to a moisture-free, ash-free, nitrogen-free and sulphur-free basis, so that the percentages of carbon, hydrogen, and oxygen added equal 100%, these three constituents being considered to be the important ones in the coal. A triangle is then drawn in which each point represents, by the distances to the sides, a given relation of C, H and O, always totaling 100%. The points representing actual coals fall in the shaded portion of the small chart, which is reproduced in the large charts following.

Chart A, opposite, represents a group of analyses collected and plotted by the *Bureau of Mines*. The coals formerly classified as anthracite, semi-anthracite, semi-bituminous, etc., fall into certain definite groups, which overlap to only a small extent. The coal analyses plotted occupy a narrow band across the diagram. The width of this band is considerably more than that due to the total error of analysis, so that it cannot be assumed that the band would narrow to a line if all errors were eliminated. This shows why former investigators have failed to reach conclusions that apply to all coals from a consideration of the ratios of carbon to oxygen, or hydrogen to oxygen alone, as coals on the two sides of the band differ distinctly, but are very close in composition. The zero "available hydrogen" line shows the percentage hydrogen which can be considered to be bound up with the percentage of oxygen in the coal. The difference between this and the percentage of hydrogen in the coal can be considered to be the available hydrogen.

There is a fairly definite relation between the calorific value of a coal and its ultimate analysis, and a similar relation between the volatile matter of a coal and its ultimate analysis. Lines drawn through dots representing coals of equal calorific value, which may be called "isocalorific" lines, are almost straight and nearly parallel, running diagonally across the band, as shown in Chart B, page 9. A correction has been made for the heating value of sulphur. Similar lines, called "isovolatile" lines, can be drawn connecting coals of equal volatile content, but the lines run transversely to the isocalorific lines.

The fact that fairly good relations are shown between the ultimate analysis and such factors as volatile content and calorific value, and possibly moisture content, can be utilized in predicting the other properties of a coal when only a few are known, as a complete analysis will not be necessary to identify a particular fuel.

The diagram containing both the isocalorific and the isovolatile lines can be used to obtain an idea of the ultimate analysis when the volatile content and the heating value are known.

The separate fields overlap but slightly. This is remarkable when it is remembered that the classification of most of the samples was made by field men more from the physical characteristics than from the analysis, and when the analyses were considered it was the proximate rather than the ultimate that influenced the classification. The sub-bituminous and lignite fields seem to overlap more than the others. This is due to the fact that in the early analyses some of the fuels which belong in the sub-bituminous fields were designated black lignite. The diagram seems to offer a satisfactory method of classifying coals according to their ultimate analyses.
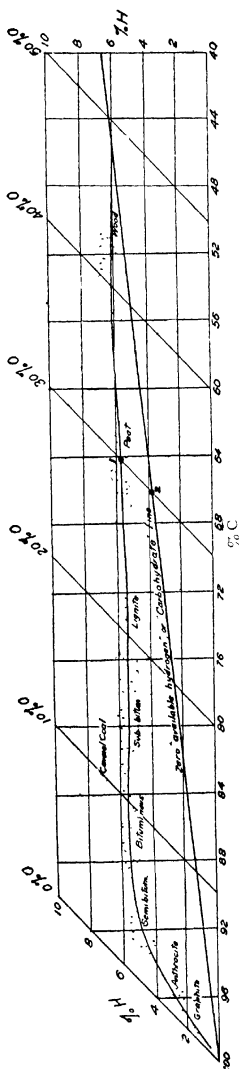
A—GROUPING OF COALS ACCORDING TO CARBON, HYDROGEN AND
OXYGEN CONTENTS. (U S Bureau of Mines, as redrawn by Sibley Journal.)
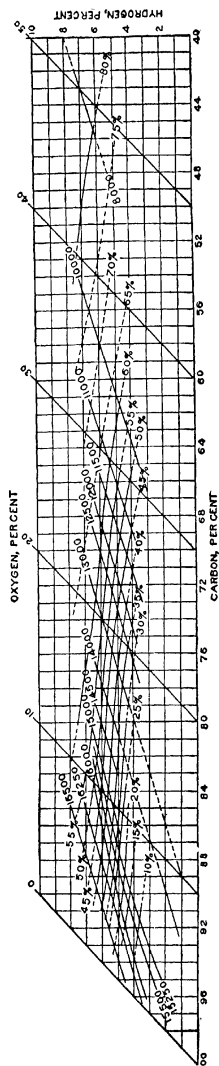
B—RELATIONS OF ISOCALORIFIC AND ISOVOLATILE LINES

Carbon per cent
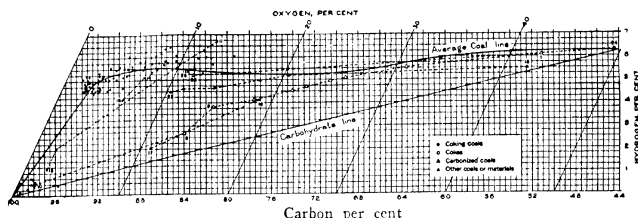
GROUPING OF COALS, ETC. ACCORDING TO CARBON, HYDROGEN AND
OXYGEN CONTENTS

The above chart shows a field in which lie coking coals. Only such
coals as were known to be used for coke were plotted by the *Bureau of
Mines*. Many other coals whose analyses have been published might have
the property of coking. Most of the coking coals lie near the sharp bend
in the average coal curve, that is, they are low in oxygen and high in
hydrogen, which tends to uphold the theory that resinous substances impart
a coking property to coal. The diagram agrees with *Parr's* criterion that
coals known to be coking are the highest in available hydrogen and *White's*
statement that coking coals show the highest hydrogen-oxygen ratio.
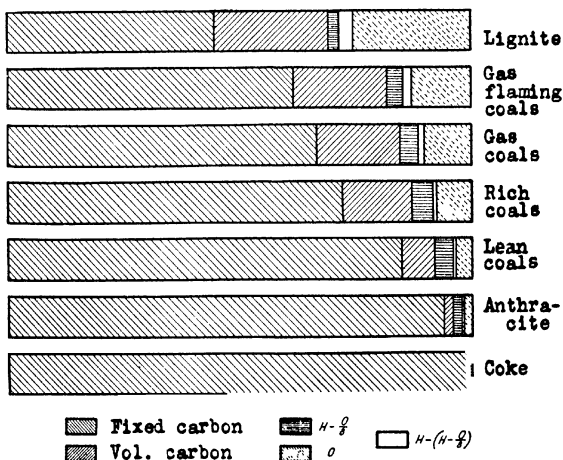
COMPOSITION OF PURE COAL SUBSTANCE

—*Z. d. V. deut. Ingr.*

Fig. *A*, from data by *Brookmann* plotted by *Schulte*, gives the composition of typical solid fuels on a water-and-ash-free basis, with total volatile constituents of the pure coal substance as abscissas, and the individual elements of the pure coal as ordinates. Both the total carbon C and the fixed (non-volatile) carbon C_f increase with the age of the coal, approaching 100% in anthracites, while the oxygen falls off. The dotted line $(H - O/8)/C$, ratio of free hydrogen to total carbon, is most favorable for coals of average gas content ("rich" coals), and falls off slightly for gas coals and strongly for coals poor in gas, checking with the observed ease of combustion of rich coals and the comparative superiority of gas coals to lean coals in this respect. The curve $(H - O/8)/C_{vol}$ would suggest that the gas developed from lean coals burns faster than that from gas coals. There is a growing belief that the oxygen in coal is not necessarily combined with hydrogen, but may be present in solid form, making its appearance when combustion is started, explaining the easy inflammability of young coals having a high oxygen content. However, the highest heating values are found with the lean coals with about the same hydrogen as the rich coals, but not so much oxygen
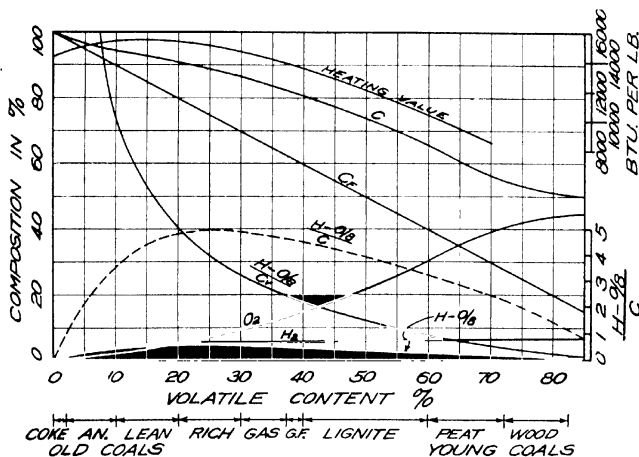
A—COMPOSITION OF PURE COAL SUBSTANCE

An. = anthracite. *Gas* = gas coal. *G F* = gas flaming coals,
C_f = fixed carbon, C_v = volatile carbon.

S. W. Parr suggests the classification of coals on the basis of the heating value and volatile content of the combustible organic matter. *BTU* and volatile matter per lb. "unit coal" are calculated from the proximate analyses, using formulas c and V on page 60.

The chart shows these values for a number of Bureau of Mines analyses, as plotted by *E. B. Vliet.* While the dividing lines have been chosen arbitrarily, there is a thinning out of points in parts of the diagram, and the author holds that the unit *BTU* is a safer criterion for designating rank than the physical characteristics by which coal is roughly classified.

Classification of Coal

Volatile Matter per Lb."Unit Coal"
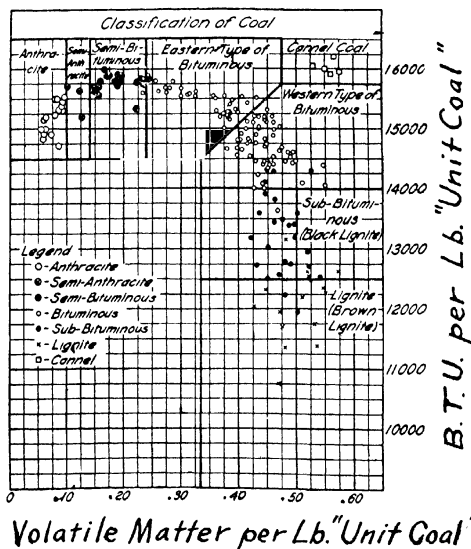
CLASSIFICATION OF COALS ON "UNIT BASIS."—*Ind. and Engg. Chem.*

The chart opposite, prepared by the *Illinois Engineering Experiment Station,* presents graphically the usual division of coal into "ranks" on the basis of the fixed carbon and volatile contents; also the heating value of each group. The lower portion represents the proximate analyses on an ash-free basis, with the lowest fixed carbon to the left, while the upper half shows the corresponding heating values, also on an ash-free (*BTU* per pound of combustible) basis. Several of the groups shown have higher heating values than has pure carbon (14,600 *BTU* per lb.), due to the presence of hydrocarbons in the volatile matter, the combustion of hydrogen developing 62,000 *BTU* per lb.
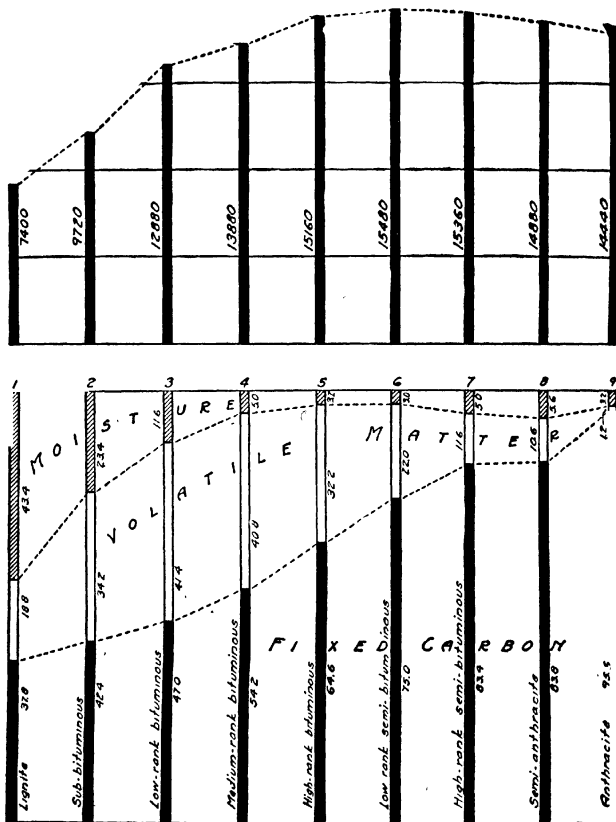
CHEMICAL COMPOSITION AND HEAT VALUE OF DIFFERENT
KINDS OF COAL.—*Ill. Eng. Exp. Sta.*

COAL SUPPLIES AND PRODUCTION

The **coal fields** of the United States are distributed as shown in the map on page 15, the estimated available reserve supplies being given in the following table by *Charles P. Berkey:*

	Area in sq. miles	Reserve in short tons
THE ANTHRACITE FIELDS		
(1) Eastern Pennsylvania	480	16,000,000,000
(2) Colorado, New Mexico..............	29	?
BITUMINOUS FIELDS of the better grade		
(3) Atlantic Coast Triassic Fields (Va., North Carolina)	210	199,000,000
(4) Appalachian Fields (Pa., Ohio, Md., Va., W. Va., Ky., Tenn., Ala. and Ga.)	69,755	530,000,000,000
(5) Eastern Interior Fields (Ind., Ill., and western Ky.)	47,000	318,000,000,000
(6) Northern Interior Field (Mich.)......	11,000	11,900,000,000
(7) Western Interior Fields (Ia., Neb., Kan., Mo., Ark., Okla., and parts of Texas)	74,900	187,500,000,000
LIGNITE AND BITUMINOUS FIELDS (chiefly low grade bituminous and lignite coals)		
(8) Gulf Coast Lignitic Field (Ark. and Texas)	2,100	20,000,000,000
(9) Great Plains and Rocky Mountain Fields (N. Dak., S. Dak., Mont., Wyo., Ida., Colo., N. Mex., Utah)..........	126,022	1,969,000,000,000
(10) Pacific Coast Fields (Wash., Ore., Cal.)	1,900	21,800,000,000
(11) Alaska	1,210	?
		3,074,399,000,000

Those for Canada are estimated as follows by *B. F. Haanel:*

Nova Scotia	2,137,000,000 tons bituminous coal	
	50,000,000 tons cannel coal	
Saskatchewan	2,412,000,000 tons lignite	
Alberta	382,500,000,000 tons lignite or sub-bituminous	
	1,197,000,000 tons low carbon bituminous	
	2,026,000,000 tons anthracite and bituminous	
	669,000,000 tons semi-anthracite	
British Columbia	23,653,000,000 tons semi-anthracite and bituminous	
	118,000,000 tons low carbon bituminous	
	60,000,000 tons lignite	
	414,822,000,000	

Total available coal reserves of the world are:

North America	5,073,431,000,000 tons
Asia	1,279,586,000,000
Europe	784,190,000,000
Oceania	170,410,000,000
Africa	57,839,000,000
South America	32,097,000,000
	7,397,553,000,000
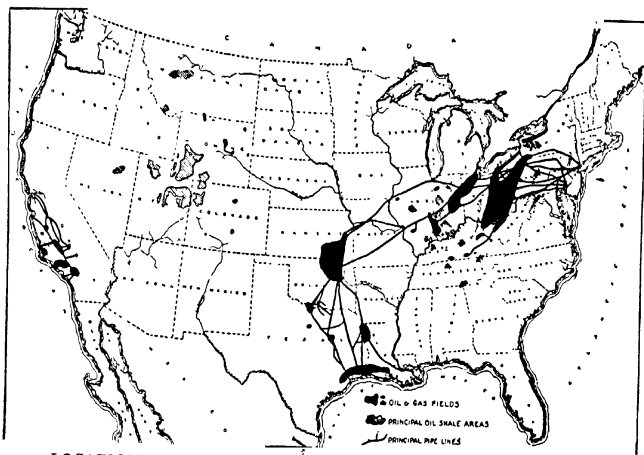
LOCATION OF PRINCIPAL OIL AND GAS FIELDS.—*Century Co.*

COAL FIELDS OF THE UNITED STATES

Sub-Bituminous   Lignite   Bituminous and Anthracite
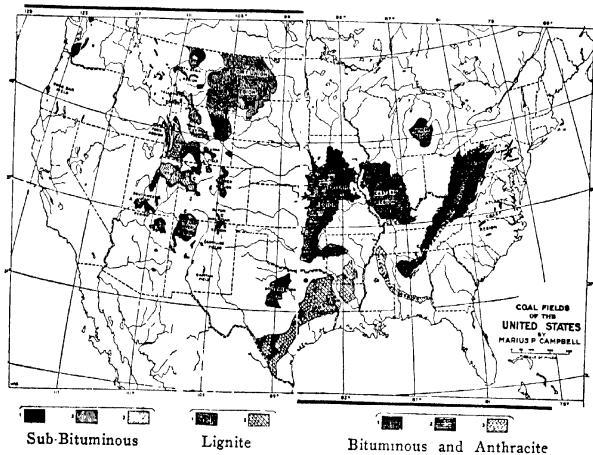
(1) Indicates areas containing workable beds
(2) Indicates areas that may contain workable beds.
(3) Areas probably containing workable beds under heavy cover, not available at present.

COAL FIELDS OF THE UNITED STATES
Adapted from *Coal Resources of the World*

COAL SUPPLY OF THE UNITED STATES—*E. W. Parker*

A = estimated supply (1000 cu. miles)
B = total used to date, C = amount mined in 1917
The small figure represents Pike's Peak, 14,108 ft. (2.7 miles) above sea level

According to *C. P. Steinmetz*, the annual coal production of the United States (including anthracite, bituminous, and oil reduced to coal according to its fuel value) increased from 110,000 tons in 1825 to 532,000,000 in 1910. The adjoining logarithmic chart shows a comparatively straight line since 1870, so that the yearly production C in tons can be represented by the formula log $C = 7.656 + .0267$ (year — 1870), the yearly increase being about 6.35%.
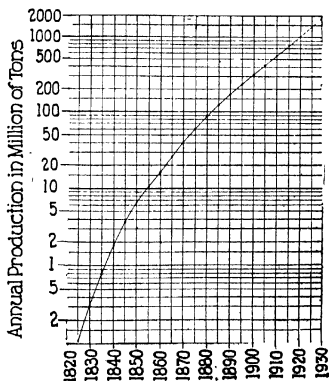
U. S. COAL PRODUCTION
—*Canadian Engr.*
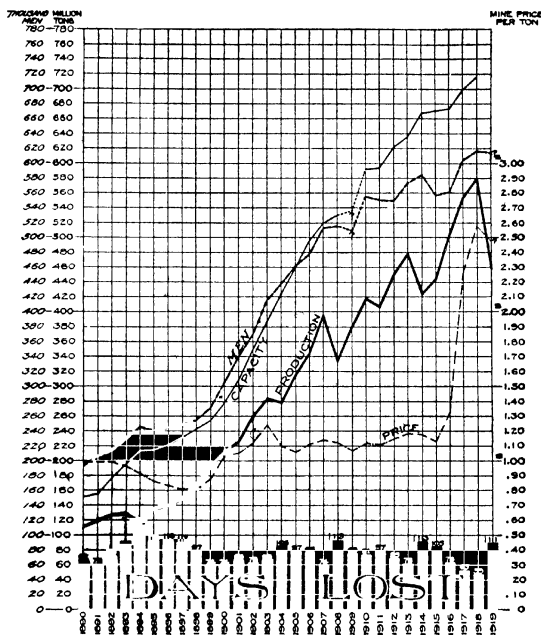
COAL MINING CONDITIONS, 1890-1919

—*Power Plant Engg.*

The above chart, by the *U. S. Geological Survey,* indicates the annual production and capacity (possible production, based on conditions of equipment) of coal mines in the United States for the past thirty years, also the number of men employed and the average prices f. o. b. mines. The "days lost" indicates the average number of days per year mines were closed, and does not include individual absences.

The charts on page 18, by *L. P. Brcckenridge,* show the production and consumption of coal for the year 1915, classified by states and industries. The small per capita consumption on the Pacific coast is due to the widespread use of hydroelectric power and the small heating requirements.

(TONS, 2000 LB)
ANTHRACITE
Pennsylvania 88,995,137

BITUMINOUS
Pennsylvania 157,965,137
West Virginia 71,784,069
Illinois 59,809,576
Ohio 22,434,691
Kentucky 21,361,614
Indiana 17,009,152
Alabama 14,927,937
Colorado 8,624,980
Virginia 8,172,596
Iowa 7,614,143
Kansas 6,624,474
Wyoming 6,544,078
Tennessee 5,730,361
All other States 29,403,798

PRODUCTION

(TONS, 2000 LB)
Railroads B 123,000,000
          A 6,200,000
Pennsylvania B 85,840,937
             A 23,282,584
Illinois B 39,976,850
         A 3,282,584
Ohio B 22,366,036
     A   600,000
New England B 20,511,967
            A 13,787,000
Exported B 18,776,690
         A 3,965,255
New York B 17,186,191
         A 20,788,000
All other B 124,273,223
          A 17,256,600

CONSUMPTION
B—Bituminous, A—Anthracite

(TONS 2000 LB)
BITUMINOUS
Industrial Steam Trade 143,765,500
Railroads 127,000,000
Domestic and Small Steam Trade 71,336,459
Bee hive Coke 42,278,516
By-product Coke 10,554,382
Exported 18,773,782
Steamship Bunker Fuel 10,701,507
Steam and Heat at Mines 9,198,681
Coal Gas 4,663,579

ANTHRACITE
Domestic 47,338,100
Steam 31,562,400
Railroads 6,200,000
Exported 3,965,255
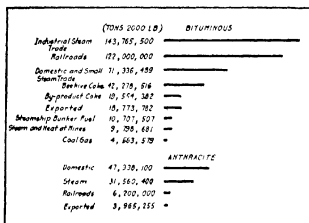
CONSUMPTION BY INDUSTRIES

(TONS, 2000 LB)
N.Y., N.J. Pa. 6.52
O., Ind., Ill., Wis., Mich. S.W. 5.31
New England 4.85
Rocky Mt. States 3.78
Minn., Iowa Mo., N.D., S.D., Neb., Kan 2.61
Ky., Tenn. Ala., Miss 2.00
Del. Md. D.C. Va., W.Va., N.C., S.C., Ga., Fla 1.72
Ark., La., Okla., Texas 0.93
Pacific Coast States 0.38
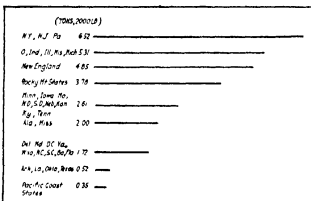
PER CAPITA CONSUMPTION
—A.S.M.E.

APPRAISAL OF COAL

To determine with utmost accuracy the ash content and heating value of delivered coal would require the burning of the entire quantity and measurement of the heat liberated, or would require crushing the entire quantity and reducing it by an elaborate scheme of successive crushings, mixings and fractional selections to portions weighing approximately 1 gram for testing in a calorimeter. Both of these procedures are impracticable, although the first can be approximated where records of evaporation, CO_2, combustible in ash and flue gas temperature are available for calculating a heat balance.

The method actually employed is to select portions from all parts of a delivery of coal and to reduce systematically the gross sample thus obtained to the quantities required by the chemist. The gross samples should be so large that the chance of admixture of pieces of slate, bone, pyrites or other impurities in an otherwise representative sample will affect but slightly the final result. It can readily be seen that it is absolutely essential that the sample be representative of the whole quantity of coal from which it is taken. The accuracy and reliability of a coal analysis are dependent upon the method and care taken in obtaining the sample.

SIZE OF COAL

While the heat value is the same whether the coal is large or small, the price of the finer grades is less than that of the larger, as special appliances must be provided for burning them.

Anthracite is almost always sized, that is, screened. The commercial names of different sizes of coals are given in the following table. The coal of a stated size will pass through the larger openings and over the smaller openings in a metal screen. See page 30.

ANTHRACITE COAL SIZES—From *Steam*

	Round Mesh Screen Diam. of Holes in Inches		Standard Square Mesh Screen Size of Holes in Inches	
	Passes through	Passes over	Passes through	Passes over
Broken	4½	3¼	4	2¾
Egg	3¼	2⅜	2¾	2
Stove	2⅜	1⅝	2	1⅜
Chestnut	1⅝	⅞	1⅜	¾
Pea	⅞	⅝	¾	½
No. 1 Buckwheat	⅝	⅜	½	¼
No. 2 Buckwheat (Rice) ...	⅜	³⁄₁₆	¼	⅛
No. 3 Buckwheat (Barley) ...	³⁄₁₆	³⁄₃₂	⅛	¹⁄₁₆
Culm..................	Residue from screening.			

Despite the greatest care used in screening, some of the coal will be under size. This should never amount to more than 15%.

There is no classification for sizes of bituminous coals which holds good in all localities. The *American Society of Mechanical Engineers* suggests the following:

EASTERN BITUMINOUS COAL

(*a*) Run-of-mine; unscreened coal taken from the mine.

(*b*) Lump; coal passing over 1¼-in. mesh bar screen.

(*c*) Nut; coal passing through a 1¼-in. bar screen, and over ¾-in. bar screen.

(*d*) Slack; coal passing through a ¾-in. bar screen.

WESTERN BITUMINOUS COAL

(*e*) Run-of-mine; unscreened coal taken from the mine.

(*f*) Lump; this group is divided in several different ways, 6-in., 3-in. and 1¼-in. lumps, according to the diameter of the circular openings over which the respective grades pass. They are also grouped as 6 x 3 in. and 3 x 1¼-in. lumps. The coal passes through the larger opening, and over the smaller.

(*g*) Nut; this is also divided into different sizes, 3-in. steam nut passes through a 3-in. diameter opening, and over a 1¼-in. opening. 1¼-in. passes through a 1¼-in. opening and over a ¾-in. opening. ¾-in. passes through a ¾-in. and over a ⅝-in. opening.

(*h*) Screenings; coal passing through ¼-in. diameter opening.

COALS OF THE UNITED STATES

(Taken from *Bureau of Mines* Bulletins.)

(*) indicates samples from car deliveries; all others are mine samples

County Bed or Local Name	Proximate Analysis "As Received"				Ultimate Analysis "As Received"					Heating Value B.T.U. per Lb. "As Received"
	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	
Alabama										
Bibb, Belle Ellen	3.16	31 05	59 56	6 23	1.20	5 33	78.28	1.37	7 59	14,141
Jefferson, Dolomite.........	3.16	25 40	67.75	3.69	.56	5 05	82.28	1.36	7.06	14,616
Jefferson, Littleton.........	2 53	26 94	59 48	11 05	.79	4.80	74 44	1.59	7 33	13,286
St Clair, Davis (Tillman Sta)	3 39	30.69	57 08	8 84	2.34	5.18	73 81	1.53	8 30	13,363
Shelby, Straven.............	3 83	32 03	58.66	5.48	.97	5 29	77 26	1.25	9 75	13,799
Tuscaloosa, Abernant........	2.62	24 18	64.11	9.09	.64	4.72	77.52	1.48	6.55	13,729
Alaska										
Alaska Peninsula, Chignik Bay, Thompson Valley.....	10.77	30 37	43.99	14 87	.70	4.98	55.27	.61	23.57	9,641
Bering River, Hartline	4.75	13.72	63 31	18.22	.62	3.14	65 93	1.32	10.77	10,820
Cook Inlet, Port Graham.....	19 96	38.73	32.46	8.85	.52	5.81	49.53	.92	34 37	8,793
Matanuska, Matanuska River	1.72	24.36	58.97	14.95	.46	4.46	70.78	1.42	7.93	12,585
Seward Peninsula, Chicago Creek..	37.82	26.14	32.16	3.88	.65	6.12	41.79	.67	45.89	
Arizona										
Navajo, Oraibi..............	9.88	32 64	46.86	10.62	1.12	5.42	62.00	1.13	19.71	10,800
Arkansas										
Logan, Paris..	2 77	14 69	73 47	9 07	2.79	4.02	78.71	1.46	3.95	13,774
Pope, Russellville	2 07	9 81	78 82	9.30	1.74	3.62	80 28	1.47	3 59	13,702
Sebastian, Greenwood.......	3 21	14.84	72.66	9.29	3.12	3.75	78.37	1.52	3.95	13,588
California										
Monterey, Stone Canyon....	6.95	46.69	40.13	6.23	4.17	6.28	66.01	1 17	16.14	12,447
Colorado										
Boulder, Lafayette..........	19 15	30.82	44.27	5.76	.25	5 93	56.38	1.08	30 60	9,616
El Paso, Pikeview..........	26 20	29.67	37.67	6.46	.30	6.13	49 36	.66	37 09	8,352
Garfield, Newcastle.........	4.45	42 05	49 56	3 94	.44	5 43	72.57	1.72	15 90	13,129
Montezuma, Cortez.........	3.89	37.01	46 58	12 52	7 04	4 96	66.19	1.16	8 13	12,341
Weld, Platteville............	28.90	28.83	37.25	5.02	.46	6.64	48.36	.93	38.59	8,465
Georgia										
Chattooga, Menlo...........	3.80	15.88	65.83	14.49	1.27	4.32	70.59	1.09	8.24	12,791
Idaho										
Fremont, Haden.............	11.45	37.24	47.01	4.30	.54	5.94	68 09	1.40	19.73	12,094
Illinois										
Clinton, *Germantown......	11.35	34 62	40 63	13 40	4.76	5.41	57 36	1.05	18.02	10,733
Franklin, Zeigler	11.82	27.66	55.10	5.42	.46	5.44	67.87	1.34	19.47	11,961
La Salle, *La Salle.........	12 39	36 89	41.80	8 92	3.92	5 85	61.29	1.00	19.02	11,399
Macoupin, *Staunton........	13 54	35 69	40.03	10.74	4 03	5.71	58.69	.95	19.88	10,807
Madison, Collinsville........	12.70	36 36	41.47	9.47	3.67	5.81	60.91	.99	19.15	10,989
Marion, *Centralia..........	9 95	34 76	42.06	13.23	3.87	5.25	59.64	1.04	16.97	10,960
Montgomery, Panama.......	13.31	33 62	41.34	11 73	3.75	5.19	59 07	.95	19.31	10,548
St. Clair, *Shiloh	11 69	35 70	39 42	13.19	4.38	5.46	57.15	.94	18.88	10,699
Saline. Harrisburg..........	6.01	32.37	54 32	7.30	1 66	5 27	71 63	1.34	12.86	12,793
Sangamon, *Auburn	16 00	32 41	37 82	13.77	4.05	5.55	53.89	.91	21.83	9,940
Williamson, Carterville......	9.18	27.30	55.40	8.12	.90	5.10	68.45	1.14	16.29	12,015
Williamson, Herrin.........	8.80	29.85	53.83	7.52	1.13	5.08	68.70	1.33	16.24	12,222
Indiana										
Clay, *Brazil..............	16 91	26.85	38.87	17.37	1 89	5.48	52 97	1.01	21.28	9,524
Greene, *Linton............	13 58	32.07	46.20	8.15	.91	5.65	63.53	1.42	20.34	11,419
Knox, *Bicknell...........	12.08	32.48	44.42	11.02	3.65	5.34	60.45	.89	18.65	11,011
Parke, *Rosedale....... ...	10.72	39.29	41.42	8.57	3.83	5.86	63.48	1.16	17.10	11,767
Pike, *Littles..............	11.12	36.98	42.55	9.35	3.78	5.63	63.01	1.13	17.10	11,549
Sullivan, Dugger...........	13.48	32.51	45.38	5.63	1.09	5.94	66.01	1.49	19.84	11,788
Vigo, *Macksville..........	12.82	34.80	42.08	10.30	3.27	5.66	61.76	1.03	18.58	11,119
Warrick, Elberfeld..........	9.69	38.59	41.04	10.68	4.79	5.39	62.36	1.28	15.50	11,412

County Bed or Local Name	Proximate Analysis "As Received"				Ultimate Analysis "As Received"					Heating Value B.T.U. per Lb. "As Received"
	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	
Iowa										
Appanoose, *Centerville ...	14 08	35 59	39 37	10 96	4 26	5 57	58 19	.90	19 82	10,723
Lucas, *Chariton...	15 39	30 49	41 49	12 63	3 19	5 74	55 81	1 14	21 49	10,242
Polk, *Altoona	13.88	36 94	35 17	14 01	6 15	5 52	54 68	.84	18 80	10,244
Wapello, *Laddsdale .	8.24	30 74	45.02	16 00	5 03	4 81	59 82	.94	13.40	11,027
Kansas										
Cherokee, *Scammon	2 50	33 80	51 25	12 45	5 68	4 91	69 07	1.20	6 69	12,900
Crawford, Fuller........ .	4 85	33 53	52 52	9 10	4 95	5 08	71 20	1 24	8 43	12,942
Leavenworth, Lansing	11 10	35 51	40 69	12 70	3 99	5 30	60 72	1 13	16 16	11,105
Linn, *Jewett ...	9.04	29.69	45.55	15 72	3 72	5.01	60.99	1 06	13.50	11,142
Kentucky										
Johnson, Flambeau	2 36	48 40	38 75	10 49	1 20	6 47	71 98	1.16	8 70	13,770
Muhlenberg, Central City	8 73	37 76	45 93	7 58	2 65	5 52	67.65	1 42	15 18	12,208
Ohio, McHenry	9 89	35 94	43 36	10 81	3 64	5 37	62 27	1.33	16 58	11,392
Pike, Hellier . . .	3 73	30 01	59 42	6 84	.56	5 07	76 30	1.06	10 17	13,649
Webster, Wheatcroft .. .	6 29	31.97	54.13	7 61	1 35	5.49	69.78	1.37	14.40	12,874
Maryland										
Allegany, Eckhart.....	2 70	14 50	74 00	8 80	1 00	4 44	79 21	1 69	4.86	13,910
Allegany, Frostburg . . .	3 20	14 50	75 60	6 70	.92	4 51	80.99	1 77	5 11	14,100
Allegany, Lord	2 26	16 05	75 86	5 83	.79	4 68	82 45	1.73	4 52	14,483
Allegany, Midland	3 10	15 50	74 50	6 90	.86	4 57	80 71	1.69	5 32	14,070
Allegany, Washington.......	3 40	15.00	75.10	6 50	1.04	4.63	80 69	1.55	5.60	14,160
Michigan										
Saginaw, Saginaw	11.91	31.50	49 75	6 84	1 24	5 84	66 56	1.19	18 33	11,781
Missouri										
Adair, Kirksville	15 98	38 15	37 18	8 69	4 12	5 90	59 09	.94	21.26	10,798
Caldwell, Hamilton	10 99	35 00	41 37	12 61	4 81	5 43	60 40	1.16	15 56	11,093
Henry, Windsor . . .	13 51	33 24	41 88	11 37	4 08	5 89	59 16	.85	18.65	10,779
Lafayette, Napoleon. ...	13 44	32 00	40 27	14 29	3 08	5 62	55 83	.98	20 20	10,232
Macon, Bevier........ .	16 25	33.38	40 97	9 40	3 41	5 75	58 25	1 05	22 14	10,625
Ray, Richmond....	13.56	34 29	40 66	11.49	3 77	5 65	58.16	1.04	19.89	10,771
Montana										
Carbon, Bear Creek........	9 67	35.92	46 39	8 02	1 64	5 52	61 66	1 48	21 68	10,832
Cascade, Geyser...... \ .·	8 76	25 72	50 36	15 16	3 91	4 40	58 93	.79	16 81	10,127
Custer, Miles	29 13	25 33	30 51	15 03	.55	5.60	40 09	.54	38.19	6,662
Fergus, Lewistown	15 35	28 27	48 08	8 30	4 53	5 42	61 15	.71	19.89	10,615
Missoula, Missoula	24.70	29 33	26.11	19 86	.85	5 56	39 04	.74	33 95	6,727
Yellowstone, Musselshell ...	16.66	27.85	48 07	7 42	1 00	5 61	59 22	.97	25,78	10,226
New Mexico										
Colfax, Raton....	2.12	36 06	50 22	11 60	.64	4 04	69 96	1 33	11 53	12,965
Lincoln, White Oaks	2 52	34 63	46 99	16.86	.76	4 97	66 65	1 32	11 56	11,956
M'Kinley, Blackrock...... ..	14.69	34.93	41 56	8 82	.79	5 82	60 93	1.12	22.52	10,809
North Dakota										
Morton, Leith........ . .	36.18	29.77	25.35	8 70	.68	6 76	39.45	.59	43.82	6,700
M'Lean, *Wilton...........	35.96	31.92	24.37	7.75	1.15	6 54	41 43	1.21	41.92	7,069
Stark, *Lehigh....	35.38	29 59	25 68	9.35	1 55	6 61	40.23	.54	41.72	6,923
Williams, *Williston	36.78	28.16	29 97	5.09	.48	6.93	41.87	.69	44.94	7,204
Ohio										
Belmont, *Bellaire...........	4.14	39.30	47 18	9 38	3.96	5.19	69 58	1.20	10 69	12,874
Guernsey, *Danford........	6 65	33 94	48 86	10 55	3 13	5 30	67.38	1.20	12 44	12,179
Jackson, *Wellston....:....	7.71	38.32	42.02	11.95	4 61	5.41	62.49	1.11	14.43	11,515
Jefferson, Amsterdam .. .,·..	3 50	37 98	51 08	7 44	3 09	5 43	73.39	1 46	9.19	13,286
Noble, Belle Valley.. ...	5 15	37.34	49 00	8 51	2 94	5 42	70 51	1 50	11.12	12,733
Perry, *Dixie........	7.55	38.00	46.08	8.37	2 84	5 48	67.02	1.29	15.00	12,128
Oklahoma										
Coal, Lehigh........	7.07	36.41	45 68	10 84	3 64	5.13	64.38	1 44	14.57	11,468
Haskell, McCurtain.....	2 70	21.07	69.88	6.35	.77	4 46	81 33	1.67	5.42	14,098
Pittsburg, Carbon..........	2.09	27.59	50.25	20 07	5.73	4.46	63 66	1.33	4.75	11,095
Pittsburg, McAlester........	3.58	32.11	59.04	5.27	.56	5 31	77.11	1.62	10.13	13,615
Oregon										
Coos, Beaver Hill.. .,...	16 10	31.10	39.63	13.17	.81	5 53	51.07	1.19	28.23	9,031

County Bed or Local Name	Proximate Analysis "As Received"				Ultimate Analysis "As Received"					Heating Value B.T.U. per Lb. "As Received"
	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	
Pennsylvania										
Allegheny, Bruceton.	2.73	36 03	54 98	6 26	1 39	5 26	76 82	1 46	8 81	13,815
Allegheny, Oak Station	3 48	35.15	55 45	5 92	1.18	5.42	75 73	1 45	10 30	13,700
Allegheny, Scott Haven	2 60	32 67	59 41	5 32	.77	5.39	78 16	1 45	8 91	14,085
Bedford, Hopewell ...	1.58	16 32	69 98	12 12	1 94	4 09	77 01	1 44	3 40	13,408
Cambria, Barnesboro.. ...	2.87	21.44	69.23	6 46	1.52	5 00	80 53	1.19	5.30	14,177
Cambria, Beaverdale... ..	3 44	16.18	73.46	6.92	1 83	4.64	80 61	1 20	4 80	14,114
Cambria, Carrolltown Road	.93	23.10	69.29	6.68	1 30	4 81	81 64	1 26	4 31	14,485
Cambria, Fallen Timber.....	3 34	24 06	62.75	9.85	1.80	4 96	76 78	1.25	5.36	13,618
Cambria, Hastings......	2 89	23 67	66 34	7.10	1.37	5 02	79.49	1.30	5.72	14,107
Cambria, Johnstown. ...	1.32	14 63	75 24	8 81	1.57	4 26	81.19	1.39	2.78	14,047
Cambria, Nanty Glo...	2 84	19 78	70 89	6 49	1 85	4.87	80 83	1.32	4 64	14,285
Cambria, Portage.........	3 52	17.32	73 27	5 89	1 06	4.78	82 06	1.23	4 98	14,278
Cambria, St. Benedict......	2 94	19.52	70 87	6 67	1.76	5 04	79.78	1.26	5.49	14,143
Cambria, Van Ormer.....	2 73	24.98	63 64	8 65	.81	4 89	78.24	1 22	6 19	13,860
Cambria, Vintondale........	3.63	18.63	71.20	6.54	1.98	4 90	80.59·1.23		4.76	14,119
Cambria, Windber...	3 30	12.50	77.90	6.33	1.04	4.46	81.65	1.27	5.25	14,340
Center, Osceola Mills .	2 08	21.46	69.87	6.59	1.99	4.92	80 58	1.29	4.63	14,274
Clarion, Blue Ball Station ..	1.90	22 00	66 30	9.80	1.95	4 66	78.05	1.14	4.40	13,760
Clearfield, Boardman.... ..	2.95	21.29	66.92	8.84	1.35	4 74	78.51	1.19	5 37	13,901
Clearfield, Philipsburg..	.90	21 59	68.49	9.02	1.99	4.57	79.49	1.31	3.62	14,060
Clearfield, Smoke Run......	3.73	20 29	68.41	7.57	1.33	4 86	78 92	1.22	6.10	13,970
Fayette, Connellsville...	3 24	27.13	62.52	7.11	.95	5.24	78 00	1.23	7.47	13,919
Indiana, Clymer...........	2.06	24.46	66.09	7.30	2.19	5 08	79 39	1.19	4.76	14,170
Indiana, Glen Campbell....	3.08	27.32	61.16	8.44	1.29	4 99	76 71	1.27	7.30	13,772
Jefferson, Sykesville........	2.44	28.44	60.68	8.44	1.32	5.07	76.91	1.31	6.95	13,732
Lackawanna, Dunmore......	3 43	6.79	78.25	11.53	.46	2.52	78.85	.77	5 87	12,782
Luzerne, Pittston...........	2 19	5 67	86.24	5.90	.57	2.70	86 37	.91	3.55	13,828
Schuylkill, Minersville	2 76	2 48	82.07	12 69	.54	2.23	79 22	.68	4.64	12,577
Schuylkill, Tower City......	3.33	3.27	84.28	9.12	.60	3 08	81.35	.79	5.06	13,351
Somerset, Jerome........	1 44	15.21	73.38	9.97	.90	4.17	79.43	1.34	4.19	13,799
Somerset, MacDonaldton...	1 03	16.03	72.57	10.37	2.22	4.29	79.17	1.24	2 71	13,700
Somerset, Windber.........	2.40	13.50	77.80	6.31	1.26	4.44	82.62	1.31	4 06	14,370
Sullivan, Lopez..........	3 16	8 59	78.08	10.17	.67	3 47	79.49	1.10	5.10	13,376
Washington, Marianna.	1 44	34.61	57.77	6.18	.78	5.23	78.76	1.44	7 61	14,242
Westmoreland, Greensburg.	2 14	30.02	58.81	9.03	1.17	5.03	76.33	1.56	6.88	13,662
Rhode Island										
Newport, Portsmouth.......	22 92	2.78	58.37	15.93	.10	2 84	58.46	.18	22.49	8,528
Providence, Cranston .	4 54	3 01	78.69	13.76	.87	.46	82.39	.12	1.75	11,624
South Dakota										
Perkins, Lodgepole..	39 16	24.68	27.81	8.35	2.22	6.60	38.02	.53	44.28	6,307
Tennessee										
Anderson, Briceville........	1 70	35.02	53.14	10.14	1.06	4.97	75.32	1.80	6.71	13,462
Campbell, Lafollette.	2 92	32 04	58.23	6.81	1.14	5.19	74.95	1.62	10.29	13,514
Rhea, Dayton..... .	1.76	27.86	49.57	20.81	.49	4.51	66.24	1.19	6.76	11,666
Texas										
Houston, Crockett.	34 70	32.23	21.87	11.20	.79	6.93	39.25	.72	41.11	7,056
Wood, Hoyt.....	33 71	29.25	29.76	7.28	.53	6.79	42.52	.79	42.09	7,348
Utah										
Carbon, Sunnyside.. ..	5.96	38.68	48.77	6.59	1.73	5.43	71.28	1.52	13.45	12,841
Emery, Emery....	3.93	40.92	49.22	5.93	.39	5.52	73.02	1.25	13.89	12,965
Iron, Cedar City.... . ..	10 35	36.33	43.70	9.62	5.82	5.13	61.24	.95	17.24	10,874
Summit, Coalville. .	14.20	36.00	44.80·	5.00	1.41	5.79	61.40	1.09	25.31	10,630

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		Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	
Virginia											
Henrico, Gayton		2.81	25.70	62.47	9 02	1.43	4 90	76 55	1 81	6.29	13,493
Lee, Darbyville		3.42	34 36	58 83	3.39	.58	5.25	77 98	1 29	11.51	14,134
Russell, Dante		2.76	34.96	56 51	5.77	.59	5 32	80 13	1 43	6 76	14,148
Tazewell, Pocahontas		3 50	15.50	76 80	4 20	.73	4 77	83 36	1 08	5 86	14,630
Wise, George		2.48	31.71	60 30	5.51	.52	5.59	79.69	1.56	7.13	14,252
Washington											
King, Black Diamond		7.98	37.69	45.95	8 38	.45	5.60	64 79	1 69	19.09	11,732
King, Cumberland		5.84	31.32	36.46	26.38	.47	4 80	52.77	1.30	14.28	9,529
Kittitas, Roslyn		3 89	37 00	46.49	12 62	.37	5 58	68 55	1.31	11.57	12,434
Pierce, Carbonado		3 81	26 60	49.33	20 26	.39	5 01	63 85	1.93	18.62	11,518
Thurston, Centralia		25.08	32 25	34.02	8.65	.82	6.37	47 26	.91	35 99	8,170
West Virginia											
Fayette, Carlisle		4.95	18.16	73.75	3.14	.82	5 09	82 15	1.48	7.32	14,434
Fayette, Fayette		3 22	22.28	71 68	2 82	.55	5 11	83 07	1 56	6 89	14,702
Fayette, Hawks Nest		5 00	24.50	67.20	3 30	.55	5 12	80 06	1.38	9 59	14,280
Fayette, Kay Moor		3 17	25.11	68 81	2 91	.52	5 09	82 59	1 63	7.26	14,584
Fayette, MacDonald		3.22	17.53	76.46	2.79	.64	5 01	84.11	1.56	5.89	14,760
Fayette, Page		3.32	28 88	62 72	5 08	.80	5 29	79.73	1.37	7.73	14,209
Fayette, Sun		2 94	19 69	68 67	8 70	1 86	4 70	77 66	1.45	5 63	13,786
Logan, Holden		1.66	32.89	59.94	5 51	.93	5 16	78 97	1.26	8.17	14,126
M'Dowell, Ashland		2 80	14.50	77.40	5 33	.64	4 56	83.39	1.03	5.05	14,593
M'Dowell, Big Four		2.30	16 98	76 21	4.51	.66	4.36	85 00	1.20	4.27	14,636
M'Dowell, Coalwood		2.19	13 91	75.25	8 65	.57	4 45	80 69	1.19	4.45	13,995
M'Dowell, Eckman		3.32	16.22	76 35	4 11	.55	4 67	83 05	1.16	6.46	14,587
M'Dowell, Ennis		3 25	14 46	78.05	4 24	.48	4 65	84 05	1.12	5.46	14,571
M'Dowell, Powhatan		2 55	13.44	78.57	5.44	.57	4 58	83 60	1.01	4 80	14,523
M'Dowell, Roderfield		2.32	16.76	69.80	11.12	1.78	4 35	77.46	1.27	4.02	13,514
M'Dowell, Worth		3.00	13.00	78 80	5.23	.48	4 46	82.84	1.05	5.94	14,500
Marion, Monongah		2.95	35 01	56.44	5 60	.67	5 33	77 89	1 38	9.13	13,862
Mercer, Coaldale		3.43	14 58	77 89	4.10	.67	4 79	83 79	1 06	5 59	14,602
Mercer, Wenonah		3.58	13 17	79.10	4.15	.56	4 90	83 50	1.07	5.73	14,598
Monongalia, Richard		1.63	28.42	62.01	7.94	.96	5.00	78.24	1.28	6 58	13,937
Preston, Masontown		1.40	26 40	62 92	9 28	1.50	4 83	77 92	1.43	5 04	13,808
Raleigh, Sophia		3.30	14.00	77.60	5.14	.63	4 60	82 94	1 41	5 28	14,490
Raleigh, Stonewall		3 02	16 06	78 75	2.17	.80	5 02	85.02	1.40	5.59	15,001
Tucker, Thomas		1.12	20.74	70.38	7.76	1.05	4.52	81.22	1.59	3.86	13,800
Wyoming											
Bighorn, Cody		17.29	31.33	45.89	5 49	.35	5 64	59.15	.85	28.52	10,055
Carbon, Hanna		11.45	42.58	39.33	6 64	.38	5.27	59 66	.94	27.11	10,890
Fremont, Hudson		21.27	32 83	42 75	3 15	.89	6.13	55 91	.75	33.17	9,779
Hot Springs, Kirby		15 86	33 01	47.39	3 74	.59	6 06	62 03	1.29	26.29	10,984
Sweetwater, Superior		16.02	33.63	47.60	2 75	.94	6 11	62 29	1.08	26 83	10,849
Sheridan, Monarch		23.88	34.33	38 44	3 35	.38	6 29	54 07	1.14	34 77	9,335

William Bartrim has assembled the following groups of analyses from the Mid-Continent fields, as representative of the fuels produced by the improved mining methods now used in that district, as distinguished from the older samples listed in the foregoing table.

PROXIMATE ANALYSES OF MID-CONTINENT COALS, "AS RECEIVED"

	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	BTU per lb.
ARKANSAS						
Franklin Co., Altus, Lump	23	17 30	79 58	2 89	90	15,263
" " Slack	.91	19 87	71 06	8 16	1 04	14,230
" Charleston, Lump	63	18 05	74.86	6 46	2 23	15 070
" " 2½ in. Screenings	.73	18 32	69 33	11 62	3 76	14,025
Sebastian Co., Hartford	60	16 00	77 50	5 90	1 10	14.600
" "	70	15 00	77 10	7 20	1 60	14.100
" "	90	15 10	77 90	6 10	1 25	14 200
" Huntington	1 90	13 59	72 25	13 26	1 55	14,120
" "	1 90	13 40	69 74	14 96	2.05	12 500
" "	1 90	13 55	70 95	13 60	1 65	13,796
KANSAS						
Cherokee Co., Scammon, Screenings	1 07	36 84	51 02	11 07		
" " "	6 55	33.79	54.71	4 95		
" " "	5 58	29 56	60 50	4 36		
" " "	4.75	34 74	52 36	8.15		
Clark Co., Lexington, Mine Run	11 45	37 85	41 72	8 98	2 17	11 800
Crawford Co., Cherokee, Screenings	4 45	36 74	38 51	20 30		
" Pittsburgh	2 25	27 46	64.10	6 19		
" " Lump	2 28	35 85	53 52	8 35	2.01	13 675
" " Nut	1 70	34 74	54 77	8 79	1 90	13,770
" " 1¼-in. Slack	2 18	33 96	53.17	10.69	2.88	13,330
MISSOURI						
Bates Co., Worland	9 29	28 98	41 83	19.90		
" Rich Hill, Lump	3 91	37 79	44 19	14.11		
Macon Co., Bevier, Raw Segs	6 45	25 00	33 43	35 10	6 10	8,152
" " Wet Slack	11 50	31 75	43 80	12 95	3 60	11,103
" " Wet Nut	12 66	36.06	42.35	8 93	4.20	11,463
OKLAHOMA						
Muskogee Co., Porum, Lump	1 7	27 2	54 2	16.9		
Okmulgee Co., Henryetta, Lump	3 95	34 69	56 08	5 28	.57	13,670
" " Nut	3 64	37 65	53 21	5 50	1 47	13,545
" " 1¼-in. Slack	3 90	30 87	53 02	12.21	1 96	12,172
Pittsburgh Co., Blocker, Mine Run	1 34	41 29	50 97	6 40	3 28	14,410
Rogers Co., Catale, Mine Run	3 47	32.99	58 51	5 03	1.40	13,570
" Collinsville	3 44	40 69	46 39	9.48	2 63	13,885

STANDARD METHOD OF SAMPLING COAL

The following method, Serial No. D 21-16, was adopted in 1916 by the *American Society for Testing Materials*, was approved in 1921 as "Tentative American Standard" by the *American Engineering Standards Committee* and forms a part of the proposed Test Code of the *American Society of Mechanical Engineers:*

It is imperative that every sample be collected and prepared carefully and conscientiously and in strict accordance with the standard methods described herein, for if the sampling is improperly done, the sample will be in error, and it may be impossible or impracticable to take another sample, but if an analysis is in error, another analysis can easily be made of the original sample.

Gross samples of the quantities designated herein must be taken whether the delivery consists of a few tons or several hundred tons, because of the following cardinal principle in sampling coal that must be recognized and understood; that is, the effect of the chance inclusion or exclusion of too many or, too few pieces of slate or other impurities in what, or from what, would otherwise have been a representative sample will cause the analysis to be in error accordingly, regardless of the tonnage sampled. For example, the chance inclusion or exclusion of 10 pounds too much or too little of im-

purities in or from an otherwise representative sample of 100 pounds would cause the analysis to show an error in ash content and heating value of approximately 10 per cent., whereas for a 1,000-pound sample, the effect would be approximately only 1 per cent., the effect being the same whether the sample is collected from a 1-ton lot or from a lot consisting of several hundred tons.

When this method of sampling is to be employed as a part of any contract or agreement, the following provisions shall be specifically agreed to by the parties to such contract or agreement: (a) The place at which the coal is to be sampled (Sec. 1); (b) The approximate size of the sample required when the standard conditions do not apply (Sec. 3); (c) The number of samples to be taken or the amount of coal to be represented by each sample when the standard conditions do not apply (Sec. 4). The method of obtaining general sample is given below, and that for the moisture sample on page 29.

I. FOR ALL DETERMINATIONS EXCEPT TOTAL MOISTURE·

1. **Time of Sampling.**—The coal shall be sampled when it is being loaded into or unloaded from railroad cars, ships, barges, or wagons, or when discharged from supply bins, or from industrial railway cars, or grab buckets, or from the coal-conveying equipment, as the case may be and as may be mutually agreed upon. If the coal is crushed as received, samples usually can be taken advantageously after the coal has passed through the crusher. Samples collected from the surface of coal in piles or bins, or in cars, ships, or barges, are generally unreliable.

2. **Size of Increments.**—To collect samples, a shovel or specially designed tool or mechanical means shall be used for taking equal portions or increments. For slack or small sizes of anthracite, increments as small as 5 to 10 pounds may be taken, but for run-of-mine or lump coal the increments should be at least 10 to 30 pounds.

3. **Collection of Gross Sample.**—The increments shall be regularly and systematically collected, so that the entire quantity of coal sampled will be represented proportionately in the gross sample, and with such frequency that a gross sample of the required amount shall be collected. The standard gross samples shall not be less than 1,000 pounds, except that for slack coal and small sizes of anthracite in which the impurities do not exist in abnormal quantities or in pieces larger than $\frac{3}{4}$ in., a gross sample of approximately 500 pounds shall be considered sufficient. If the coal contains an unusual amount of impurities, such as slate, and if the pieces of such impurities are very large, a gross sample of 1,500 pounds or more shall be collected. The gross sample should contain the same proportion of lump coal, fine coal, and impurities as is contained in the coal sampled. When coal is extremely lumpy it is best to break a proportional amount of the lumps before taking the various increments of a sample. Provision should be made for the preservation of the integrity of the sample.

4. **Quantity Represented.**—A gross sample shall be taken for each 500 tons or less, or in case of larger tonnages for such quantities as may be agreed upon.

5. **Preparation.**—After the gross sample has been collected, it shall be systematically crushed, mixed, and reduced in quantity to convenient size for transmittal to the laboratory. The sample may be crushed by hand or by any mechanical means, but under such conditions as shall prevent loss or the accidental admixture of foreign matter. Samples of the quantities indicated in Table 1 following shall be so crushed that no pieces of coal and impurities will be greater in any dimension, as judged by the eye, than specified for the sample, before division into two approximately equal parts.

BUREAU OF MINES

BULLETIN 118 PLATE 4

NOTE

SELECT A HARD, CLEAN SURFACE, FREE OF CRACKS AND PROTECTED FROM RAIN, SNOW, WIND, AND BEATING SUN. DO NOT LET CINDERS, SAND, CHIPPINGS FROM FLOOR, OR ANY OTHER FOREIGN MATTER GET INTO THE SAMPLE. PROTECT SAMPLE FROM LOSS OR GAIN IN MOISTURE

1. Crush 1,000-pound sample on hard, clean surface to 1" size

2. 1,000-pound sample crushed to 1" and coned

3. Mix by forming long pile. A—spreading out first shovelful B—long pile kompleted

4. Halving by alternate shovel method. Shovelfuls 1, 3, 5, etc., reserved as 5, A, 2, 4, 6, etc. rejected as B

5. Long pile divided into two parts, A—reserve, B—reject

6. Crush 500-pound sample (fig 5, A) to ¾" size

7. 500 pounds crushed to ¾" and coned

8. Mix by forming long pile. A—spreading out first shovelful. B—long pile completed

9. Halving by alternate shovel method. Shovelfuls 1, 3, 5, etc., reserved as 10, A, 2, 4, 6, etc. rejected as B

10. Long pile divided into two parts, A—reserve, B—reject

11. Crush 250-pound sample (fig 10, A) to ½" size

12. 250-pounds crushed to ½" and coned

13. Mix by forming new cone

14. Quarter after flattening cone

15. Sample divided into quarters

16. Crush 125-pound sample (fig 15, A, A) on blanket to ¼" size

17. Retain opposite quarter A, A. Reject quarter B, B

18. Mix by rolling on blanket

19. Form cone after mixing

20. Quarter after flattening cone

21. Sample divided into quarters

22. Retain opposite quarters A, A. Reject quarters B, B
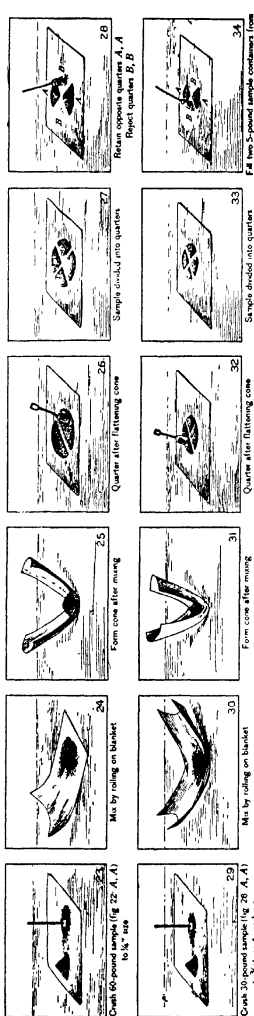
METHOD OF PREPARING A SAMPLE OF COAL BY HAND ON A BLANKET MEASURING ABOUT 6 BY 8 FEET. BROOM AND RAKE. THE NECESSARY TOOLS ARE A SHOVEL, TAMPER, CRUSHED, SO THAT ALL LUMPS WILL BE CRUSHED. THE COAL IS RAKED WHILE BEING COAL EACH TIME AFTER SAMPLE IS HALVED OR QUARTERED. FLOOR OR BLANKET IS SWEPT CLEAN OF DISCARDED

TABLE 1.—LARGEST SIZES OF COAL AND IMPURITIES ALLOWABLE IN SAMPLES RANGING FROM 1,000 TO 30 LB. IN WEIGHT.

Weight of sample to be divided, pounds	
1,000 or more..........	1 inch
500	¾ inch
250	½ inch
125	⅜ inch
60	¼ inch
30..	³⁄₁₆-in., to pass No. 4 sieve

The method of reducing by hand the quantity of coal in a gross sample shall be carried out as prescribed below, even should the initial size of the coal and impurities be less than in Table 1.

6. **Hand Preparation.**—The progressive reduction in the weight of the sample to the quantities indicated in Table 1 shall be done by the following methods, which are illustrated on this page:

(a) **Mixing and Reduction by Discarding Alternate Shovelfuls.** —The alternate-shovel method of reducing the gross sample shall be repeated until the sample is reduced to approximately 250 pounds; and care shall be observed before each reduction in quantity that the sample has been crushed to the fineness prescribed in Table 1.

The crushed coal shall be shoveled into a conical pile (figs. 2 and 7) by depositing each shovelful of coal on top of the preceding one, and then formed into a long pile in the following manner:

The sampler shall take a shovelful of coal from the conical pile and spread it out in a straight line (figs. 3, *A*, and 8, *A*) having a width equal to the width of the shovel and a length of 5 to 10 feet. His next shovelful shall be spread directly over the top of the first shovelful, but in the opposite direction, and so on back and forth, the pile being occasionally flattened until all the coal has been formed into one long pile (figs.

3, *B*, and 8, *B*)   The sampler shall then discard half of this pile, proceeding as follows:

Beginning on one side of the pile, at either end, and shoveling from the bottom of the pile, the sampler shall take one shovelful (shovelful No. 1, figs 4 and 9) and set it aside; advancing along the side of the pile a distance equal to the width of the shovel, he shall take a second shovelful (shovelful No 2, figs. 4 and 9) and discard it; again advancing in the same direction one shovel width, he shall take a third shovelful (shovelful No 3, figs 4 and 9) and add it to the first   Shovelful No. 4 (figs. 4 and 9) is to be taken in a like manner and discarded, the fifth shovelful (No. 5, figs 4 and 9) retained, and so on, the sampler advancing always in the same direction around the pile, so that its size will be gradually reduced in a uniform manner.   When the pile is removed, about half of the original quantity of coal should be contained in the new pile formed by the alternate shovelfuls which have been retained (figs 5, *A*, and 10, *A*, show the retained halves, and 5, *B*, and 10, *B*, the rejected halves).

(*b*)   **Mixing and Reduction by Quartering.**—After the gross sample has been reduced by the above method to approximately 250 lb, further reduction in quantity shall be by the quartering method.   Before each quartering, the sample shall be crushed to the fineness prescribed in Table 1.

Quantities of 125 to 250 lb. shall be thoroughly mixed by coning and reconing (figs. 12 and 13); quantities less than 125 lb. shall be placed on a suitable cloth, measuring about 6 by 8 feet, mixed by raising first one end of the cloth and then the other (figs. 18, 24, 30), so as to roll the coal back and forth, and after being thoroughly mixed shall be formed into a conical pile by gathering together the four corners of the cloth (figs. 19, 25, and 31).   The quartering of the conical pile shall be done as follows

The cone shall be flattened, its apex being pressed vertically down with a shovel or board, so that after the pile has been quartered each quarter will contain the material originally in it.   The flattened mass, which shall be of uniform thickness and diameter, shall then be marked into quarters (figs. 14, 20, 26, and 32) by two lines that intersect at right angles directly under a point corresponding to the apex of the original cone.   The diagonally opposite quarters (*B*, *B* in figs. 16, 22, 28, and 34) shall then be shoveled away and discarded and the space that they occupied brushed clean   The coal remaining shall be successively crushed, mixed, coned, and quartered, until the sample is reduced to the desired quantity.

(*c*)   The 30-lb. quantity (fig. 29) shall be crushed to $\frac{3}{16}$-in. size or to pass a No. 4 sieve, mixed, coned, flattened and quartered.   The laboratory samples shall include all of one of the quarters, or all of two opposite quarters (fig. 34), as may be required.   The laboratory sample shall be immediately placed in a suitable container and sealed in such a manner as to preclude tampering.

The proposed *A S. M E. Test Code* substitutes for the above paragraph the following: The laboratory sample shall be immediately divided into two parts, placed in suitable containers, and sealed in such a manner as to preclude tampering.   One of these shall be sent to the laboratory for analysis, and the other retained at the plant until satisfactory analysis of the laboratory sample has been completed and reported.

It also provides that as an alternative method for cases in which less accurate results are permissible, a smaller total weight of fuel sample may be collected, it being, of course, understood that the probable error in sampling varies inversely with the weight of sample collected.

7. Mechanical Preparation.—Only such mechanical means as will give equally representative samples shall be used in substitution for the hand method of preparation herein standardized.

The proposed *A. S. M. E. Test Code* adds the following

Coke samples shall be treated as coal samples, but iron or steel grinding mills must be used Following the grinding process, the ground sample shall be run under a magnet to separate out iron which results from the abrasive action of the coke

In collecting and reducing coke samples all instruments used for crushing shall be made of iron or steel, so that in later preparation of sample in laboratory, particles mixed with the coke sample, due to its abrasive action on crushing instruments, may be separated out by running the ground sample under a magnet

II. FOR THE DETERMINATION OF TOTAL MOISTURE

8. Collection of Moisture Sample.—The special moisture sample shall weigh approximately 100 lb, and shall be accumulated by placing in a water-proof receptacle with a tight-fitting and waterproof lid small equal parts of freshly taken increments of the standard gross sample The accumulated moisture sample shall be rapidly crushed and reduced mechanically or by hand to about a 5-lb. quantity, which shall be immediately placed in a container and sealed air-tight and forwarded to the laboratory without delay.

9. Use of Standard Sample.—Only when equally representative results will be obtained shall the standard gross sample be used instead of the special moisture sample for the determination of total moisture.

METHOD USED BY *BUREAU OF MINES* FOR SEALING SHIPPING CAN WITH ADHESIVE TAPE

The proposed *A. S. M. E. Test Code* provides that for determining **fuel size** the gross samples collected as explained in Sec. 6, page 27, or equivalent samples, shall be used. Such samples before they have been broken up are passed over and through standard screens, taking care to prevent breaking up the coal, but continuing the shaking process long enough to give complete separation. For bituminous coal, the first screen in the series shall be large enough so that not more than 5% by weight of total sample shall remain on the screen. The last screen size (smallest opening) in the scale will be such that not more than 20% will pass through. The following report is typical.

Over 5 in.	5%
On 2½ in., through 5 in.	10
On 1¼ in., through 2½ in.	40
On ⅝ in., through 1¼ in.	30
Remainder	15

For anthracite, the gross samples, or equivalent samples, are passed over and through screens having the following sizes of *round-hole* perforations:

Screen No	1	2	3	4	5	6	7	8
Diam., in.	4½	3¼	2⅜	1⅝	⅞	⁹⁄₁₆	⁵⁄₁₆	³⁄₁₆

In designating the size of anthracite fuel used for test purposes (particularly for power boilers using steam sizes of anthracite) the use of trade names should be discouraged. Where, however, it is desired to refer to fuel by trade-size designation, the size of the perforations in the screens through and over which the coal must pass should be definitely stated. Furthermore, limits should be set to the permissible percentages of coal as shown by the sample that will not go through the larger-size screen and that will go through the smaller-size screen. This is of importance when the size of coal is to be specified in advance of the conduct of the test and particularly where guarantees are to be made when using a certain size of coal. See page 19.

The *Bureau of Mines* has developed a **ladle** to take the place of the shovel in sampling car shipments. This ladle is 1 foot in diameter at the top and 9 in. in diameter at the bottom. It is 9½ in. deep, and holds between 25 and 30 lb. The handle is 5 feet long. In sampling shipments delivered from hopper cars, the ladle is rested on the rail, or on the chain that supports the car gates. Two ladlefuls are taken from each car, one on either side. The ladle is shifted if possible, to get coal from different parts of the stream. It can be used only where the discharge of the coal is not very rapid.

As wagon and railroad cars may arrive irregularly, and the coal be unloaded intermittently, a metal or wooden receptacle of a size to hold a gross sample of at least 1,000 pounds, with a tight-fitting lid which can be locked, is required. In sampling cargo deliveries, buckets holding from 60 to 70 pounds may prove more satisfactory, as the samples are usually worked down as the loading progresses. The buckets are convenient for carrying the coal to a place convenient for preparing the gross sample.

At the *State Capitol* power plant at *Madison, Wis.*, the coal is unloaded from the dump cars into a hopper and sent to a crusher. A sampler

driven from one of the sprockets takes a scoopful of coal at regular intervals. This is deposited on a steel sampling board, about 100 pounds being taken from each car. The samples are crushed, mixed and quartered, the process being repeated until a composite sample of about 10 pounds remains, no piece larger than a filbert. From this sample four jars are filled and sealed for the laboratory, each marked with a serial number, and the car weight.

If the sample is properly crushed and mixed before placing in the cans and properly distributed in the cans, two laboratories should check well within 1%.

A mine sample analysis will usually indicate a better grade of coal as regards ash content and heat value than is determined by a sample from a commercial shipment. Different mines have different practices in regard to rejecting impurities. The moisture content will also be different The calorific value of the delivered sample should be not more than 1% lower than the calorific value of the mine sample, provided there is not an excessive difference in the ash and sulphur. The ash variation should be less than 10% and the sulphur variation less than 3%.

PREPARATION OF LABORATORY SAMPLE

The proper preparation of the laboratory sample is as important as the proper taking and reducing of the gross sample of coal.

The directions D 22-24 of the *American Society for Testing Materials,* the *American Chemical Society* and the *American Society of Mechanical Engineers* for the preparation of laboratory samples call for the following apparatus:

Air-Drying Oven.—The oven is to be used for air-drying wet samples and may be of the form shown in Fig. 1. This is not absolutely necessary but is economical where many wet samples are received.

Galvanized-Iron Pans 18 by 18 by 1 5 in. Deep—For air-drying wet samples.

Balance or Solution Scale—For weighing the galvanized-iron pans with samples. It should have a capacity of 5 kg. and be sensitive to 0.5 g.

Jaw Crusher.—For crushing coarse samples to pass a No. 4 sieve.

Roll Crusher or Coffee-Mill Type of Grinder—For reducing the material passing a No. 4 sieve to pass a No. 20 sieve. The coffee-mill type of grinder should be entirely enclosed and have an enclosed hopper and a receptacle capable of holding 10 lb. of coal. This is to reduce the moisture losses while crushing.

Abbé Ball Mill, Planetary Disk Crusher, Chrome-Steel Bucking Board, or any Satisfactory Form of Pulverizer.—For reducing the material passing a No. 20 sieve to pass a No. 60 sieve. The porcelain jars for the ball mill should be approximately 9 in. in diameter and 10 in. high. The flint pebbles should be smooth, hard and well rounded.

A Large Riffle Sampler, with ½ or ⅝-in. Divisions.—For reducing the sample passing a No 4 sieve to 10 lb. (Fig. 2).[1]

A Small Riffle Sampler, with ¼ or ⅛-in Divisions—For dividing down the material passing No. 20 and No. 60 sieves to a laboratory sample (Fig. 2).

An 8-in. No. 60 Sieve of the United States Standard Sieve Series,[2] with Cover and Receiver.

Containers for Shipment to Laboratory.—Samples in which the moisture content is important should always be shipped in moisture-tight containers A galvanized-iron or tin can with a screw top which is sealed with a rubber gasket and adhesive tape is best adapted to this purpose. Glass fruit jars sealed with rubber gaskets may be used, but require very careful packing to avoid breakage in transit. Samples in which the moisture content is of no importance need no special protection from loss of moisture.

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[1]E. E. Somermeier, "Coal, Its Composition, etc.," McGraw-Hill Book Co (1912).

[2]For detailed specifications for this sieve, see U. S. Bureau of Standards, *Letter Circular No. 74.*
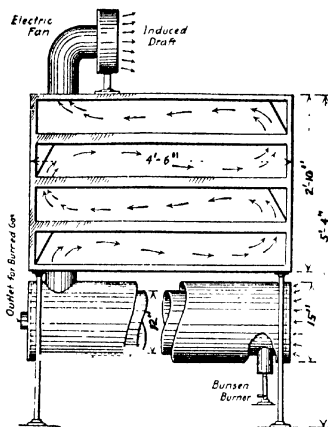
1. DRIER FOR COARSE SAMPLES

The outlet for air at the top may be connected with a chimney or any other device which will furnish a suitable draft.—*Geological Survey of Ohio.*
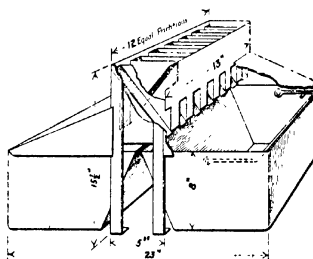
2. RIFFLE SAMPLER
Geological Survey of Ohio.

When Coal Appears Dry, if the sample is coarser than will pass completely a No. 4 sieve and larger in amount than 10 lb., quickly crush it with the jaw crusher to pass a No. 4 sieve and reduce it on the larger riffle sampler to 10 lb.,[1] then crush at once to pass a No. 20 sieve by passing through rolls or an enclosed grinder, and take, without sieving, a 60-g. total moisture sample, immediately after the material has passed through the crushing apparatus. This sample should be taken with a spoon from various parts of the product passing a No. 20 sieve, and should be placed directly in a rubber-stoppered bottle. Thoroughly mix the main portion of the sample, reduce on the small riffle sampler to about 120 g., and pulverize to pass a No. 60 sieve by any suitable apparatus without regard to loss of moisture. After all the material has been passed through the No. 60 sieve, mix and divide it on the small riffle sampler to 60 g. Transfer the final sample to a 4-oz. rubber-stoppered bottle. Determine moisture in both the No. 60 sieve sample and the No. 20 sieve sample by the method given on page 35. Compute the analysis of the coal passing a No. 60 sieve which has become partly air-dried during sampling, to the dry-coal basis, by dividing each result by 1 minus its content of moisture. Compute the analysis of the coal "as received" from the dry-coal analysis by multiplying by 1 minus the total moisture found in the sample passing a No. 20 sieve.

[1] If the sample is crushed to pass a No. 6 sieve it may be reduced to 5 lb.

When Coal Appears Wet, spread the sample on tared pans, weigh, and air-dry at room temperature, or in the special drying oven, shown in Fig. 1, at 10 to 15° C. above room temperature, and weigh again. The drying should be continued until the loss in weight is not more than 0.1% per. hr. Complete the sampling as above. Correct the moisture found in the air-dried sample passing a No. 20 sieve to total moisture "as received," as follows:

$$\frac{100 - \% \text{ air-drying loss}}{100} \times (\% \text{ moisture in air-dried sample passing a No 20 sieve})$$

$$+ (\% \text{ air-drying loss}) = (\text{total moisture "as received"})$$

Compute the analysis to "dry-coal" and "as-received" bases as under dry coal, using for the "as-received" computation the total moisture as found by the formula in place of the moisture found in the coal passing a No. 20 sieve.

Freshly mined or wet coal loses moisture rapidly on exposure to the air of the laboratory, hence the sampling operations between opening the container and taking the total-moisture sample passing a No 20 sieve must be conducted with the utmost dispatch and with minimum exposure to air. The accuracy of the method of preparing laboratory samples should be checked frequently by resampling the rejected portions and preparing a duplicate sample. The ash in the two samples should not differ more than the following limits.

No carbonates present ...	0 4%
Considerable carbonate and pyrite present	0 7%
Coals with more than 12% ash, containing considerable carbonate and pyrite .	1 0%

It has been found that if a 4 oz. sample of fine coal containing heavy foreign matter in the form of slate, pyrites, etc, is allowed to stand, the heavy particles will tend to settle to the bottom. This tendency is more pronounced if the place of storage is subject to vibration, such as that caused by heavy machinery.

The pulverized sample should be very thoroughly mixed before the small amounts are taken for the actual analysis. The Fuel Inspection Laboratory of the *Bureau of Mines* is equipped with a mixing wheel on which the bottles are placed at 45°, and rotated at about 30 to 40 rpm. The wheel must not rotate so rapidly that the centrifugal force has an appreciable effect on the mixing.

The abrasion of the porcelain container and the flint pebbles in a ball mill is very slight. After 250 grindings, it was found that the pebbles showed a loss of weight equivalent to .004 of 1% of the coal that had been ground. After 100 grindings, the jar showed a loss of weight equivalent to 0.033% of the coal that had been ground. The total increase in the ash content was never more than .04 of 1%, which is less than the analytical error in the determination of ash.

The chemist's sample must have a composition that is an average of the entire lot of coal. "Skill and training are just as important in taking and reducing the samples as in making the chemical analysis."

The accuracy of any method of sampling should be tested frequently by taking and analyzing two samples independently.

In the power plant of the *Wisconsin Capitol*, the contents of a three-quart fruit jar is ground in a coffee mill, so that it will pass entirely through a 40-mesh sieve. If much work is to be done, a small roll crusher should be used. The sample is then quartered and reduced to a 4-oz. sample, which is put in a rubber-stoppered glass bottle bearing a number. This constitutes the laboratory sample.

Old pulverized samples cannot be regarded as representative. The *Bureau of Mines* took portions of the finely divided coal prepared for analysis and kept them in securely stoppered bottles. They were weighed and analyzed from time to time over a period of a year. There was in every instance a gain of weight, and yet the moisture content usually decreased The gain in weight is due to oxidation, and the moisture loss to actual loss by fixation in connection with the oxidation. In every case these changes were important. The smallest gain in weight was 0.53%, while one was 2.56%, with a decrease of 205 calories in the heat value. The change in weight corresponded to a decrease in heat value of 144 calories. The final calorific value therefore is 61 calories lower than accounted for by the change of weight.

The coal may change in moisture during the process of pulverization. In the *Bureau of Mines* laboratory it was found that samples ground on a bucking board would either gain or lose moisture, depending upon the thoroughness of the preliminary drying and upon the moisture content of the air of the laboratory. From this standpoint the method of grinding in a ball mill is much more satisfactory and reliable than any other, even though there is a slight change in moisture content during the grinding.

The moisture change in samples prepared and stored in different ways is quite great. A 1-gram sample of fine coal, previously undried, lost 2% in weight in 5 minutes, and 8% in 24 hours, when exposed to the air on a watchglass. Samples kept in an open bottle may lose considerable weight. One such sample lost 0.7% in 24 hours, 2% in 72 hours, and almost 5% in 24 days.

The loss in a well-dried sample is not nearly as large. A 1-gram sample lost 0.93% in 5 minutes, but after that the loss was very slight. This indicates the extreme sensitiveness of finely-ground coal to changes in moisture, and shows the need of placing the stopper tightly in the bottle.

After 72 days the 1-gram sample of coal previously undried had lost a decidedly greater percentage than the 10-gram sample of the same pulverized coal, and about twice as much as the sample in the open bottle. It is quite certain that the change in weight is not entirely due to moisture loss, but to oxidation as well.

PROXIMATE ANALYSIS

The true test of any coal is the burning of it. On the other hand, the chemical character and quality of a coal is a reliable indication of what may be expected from its use. Coal can be purchased under specifications as to the chemical content, and knowledge of the chemical content makes it possible to determine whether the coal specified has been delivered. In a large manufacturing plant coal and cinder analyses should be made daily. An average analysis for the month is obtained by multiplying each analysis by the number of cars it represents, and dividing the sum by the total num-

ber of cars. Analyses should be made by a careful and experienced person having proper facilities, as will be apparent from the following. There are two different kinds of coal analysis:

1. The proximate analysis determines the moisture, volatile matter, fixed carbon and ash as percentages This information is sufficient for most uses

2. The ultimate analysis is a chemical analysis giving the percentages of carbon (C), hydrogen (H), nitrogen (N), sulphur (S) and ash.

Sulphur is usually determined in connection with a proximate analysis, but is not given as a part of the 100%

A determination of the heating value of coal is nearly always made in connection with a proximate analysis, and usually in connection with an ultimate analysis, although the heat value can be very closely computed from the latter.

The following definitions are used in connection with proximate analyses:

Fixed carbon is the combustible remaining after distillation. It is *not* the same as the total carbon found by ultimate analysis

Combustible is arbitrarily defined as that portion of the dry coal left after subtracting ash and moisture

Volatile matter is the total combustible less the fixed carbon, and includes gases, hydrocarbons, free oxygen and nitrogen, although the latter two are not combustible.

Ash is the residue remaining after the moisture and volatile have been driven off and the fixed carbon ignited

Moisture is arbitrarily considered to be the loss in weight of a sample of coal when dried at a given temperature for a given length of time

The proposed *A. S. M. E. Test Code* states that the proximate analysis report shall give the weight of Moisture, Volatile Matter, Fixed Carbon and Ash, on the "as received" or "as used" basis.

Determination of Moisture.—The method D 22-24 of the *A S.T.M.*, *A.C.S. and A.S.M.E.*, calls for the following apparatus.

Moisture Oven—This must be so constructed as to have a uniform temperature in all parts and a minimum of air space. It may be of the form shown in Fig. 3. Provision must be made for renewing the air in the oven at the rate of two to four times a minute, with the air dried by passing it through concentrated H_2SO_4.

Capsules with Covers.—A convenient form, which allows the ash determination to be made on the same sample, is a porcelain capsule $\frac{7}{8}$ in deep and $1\frac{3}{4}$ in. in diameter; or a fused silica capsule of similar shape. This is to be used with a well-fitting flat aluminum cover, illustrated in Fig 4 Glass capsules with ground-glass caps may also be used. They should be as shallow as possible, consistent with convenient handling.

Sample Passing No. 60 Sieve, heat the empty capsules under the conditions at which the coal is to be dried, stopper or cover, cool over concentrated H_2SO_4, sp gr. 1 84, for 30 min., and weigh. Dip out with a spoon or spatula from the sample bottle approximately 1 g. of coal; put this quickly into the capsule, close, and weigh at once. An alternative procedure (more open to error), after transferring an amount slightly in excess of 1 g., is to bring to exactly 1 g. in weight (± 0.5 mg.) by quickly removing the excess weight of coal with a spatula. The utmost dispatch must be used in order to minimize the exposure of the coal until the weight is found. After removing the covers, quickly place the capsules in a pre-heated oven (at 104 to 110° C.) through which passes a current
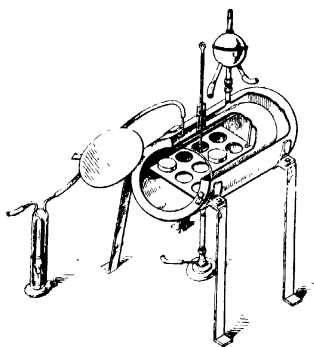
3. TOLUENE OR GLYCERIN-AND-
WATER OVEN FOR DETERMINING
MOISTURE
Bureau of Mines.
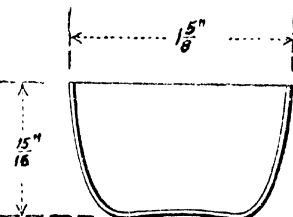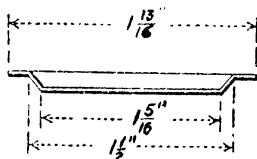
4. PORCELAIN CAPSULE WITH
FLAT ALUMINUM COVER.

of air dried by concentrated H_2SO_4. Close the oven at once and heat for 1 hr. Then open the oven, cover the capsules quickly, and place them in a desiccator over concentrated H_2SO_4. When cool, weigh.

Sample Passing No. 20 Sieve, use 5-g. samples, weighed with an accuracy of 2 mg., and heat for 1½ hr.; the procedure is otherwise the same as with the sample passing a No. 60 sieve. Methods of greater accuracy for the determination of moisture are given in the preliminary report, 1914.

The permissible differences in duplicate determinations are as follows:

	Same Analyst	Different Analysts
Moisture under 5%	0 2%	0 3%
Moisture over 5%	0 3%	0 5%

The moisture contained in coal is in two conditions. The first is extraneous moisture, and is taken up from water percolating through the mine, from atmospheric precipitation, or from washing water. The relative amount depends largely upon the size of the coal. Slack coal retains 4 to 10 times as much superficial moisture as screened lump exposed to the same condition. The remainder of the moisture is inherent in the coal. It is part of the original vegetable matter from which the coal was derived. The analysis does not distinguish between the two forms.

Mine samples contain little extraneous moisture, so that the determination shows closely the **inherent moisture.** Its amount is shown approximately by the following figures:

Eastern Appalachian bituminous coals, 2 to 4%.
Western Appalachian and Ohio coals, 4 to 10%.
Indiana, Illinois, Iowa and Missouri coals, 8 to 17%.
Sub-bituminous coals, 12 to 30%.
Lignite, 25 to 45%.

The moisture content is the distinguishing feature between sub-bituminous and lignite coals.

Volatile Matter Determination.—The objection has sometimes been made that the term "volatile matter" properly includes moisture. "Volatile combustible matter" would also be incorrect, as this would imply that all of the volatile matter exclusive of moisture was combustible, whereas it includes such non-combustibles as carbon-dioxide and nitrogen. From one-tenth to one-third of the volatile matter is non-combustible. A conservative estimate places the carbon in volatile matter at one-half by weight.

The volatile matter does not represent any definite compound in the coal. The method of determination and the temperature used are wholly conventional

The *A.S.T.M.*, *A.C.S* and *A.S.M.E.* Standard Method D22-24 for determination of volatile matter is as follows. Apparatus required·

Platinum Crucible with Tightly Fitting Cover—The crucible should be of not less than 10 nor more than 20-c c capacity, of not less than 25 nor more than 35 mm in diameter, of not less than 30 nor more than 35 mm in height.

Vertical Electric Tube Furnace, or a Gas or Electrically Heated Muffle Furnace—The furnace may be of the form as shown in Fig 5 It is to be regulated to maintain a temperature of 950° C. ± 20° C in the crucible, as shown by a thermocouple kept in the furnace. If the determination of volatile matter is not an essential feature of the specifications under which the coal is bought, a Meker burner may be used.

Weigh 1 g of the coal in a weighed 10 to 20-c c. platinum crucible, close with a capsule cover, and place on platinum or nichrome-wire supports in the furnace chamber, which must be at a temperature of 950° C. ± 20°C. After the more rapid discharge of volatile matter has subsided, as shown by the disappearance of the luminous flame, tap the cover lightly to more perfectly seal the crucible and thus guard against the admission of air. After heating exactly 7 min., remove the crucible from the furnace and, without disturbing the cover, allow it to cool. Weigh
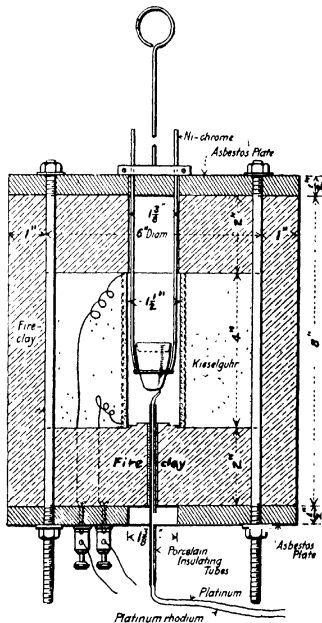
5. ELECTRIC TUBE FURNACE FOR DETERMINING VOLATILE MATTER.

For 110-volt A. C., 60 ft. of Nichrome Wire. No. 17 B & S. gage, will give the required temperature. The temperature must be controlled by an external resistance.—*Bureau of Mines.*

as soon as cold. The loss of weight minus moisture equals the volatile matter. Mechanical losses are incurred on suddenly heating peat, sub-bituminous coal, and lignite; therefore they must be subjected to a preliminary gradual heating for 5 min.; this is best done by playing the flame of a burner upon the bottom of the crucible in such a manner as to bring about the discharge of volatile matter at a rate not sufficient to cause sparking. After the preliminary heating, transfer the crucible to the volatile-matter furnace and heat for 6 min. at 950° C. as in the regular method.

The permissible differences in duplicate determinations are as follows:

	Same Analyst	Different Analysts
Bituminous coals	0 5%	1.0%
Lignites	1 0%	2.0%

The cover should fit closely enough so that the carbon deposit from bituminous and lignite coals does not burn away from the under side. Regulation of temperature to within the prescribed limits is important.

The 10 c.c. platinum crucible is used in preference to the 30 c.c. crucible formerly used, because the loss of weight due to oxidation of the carbon is thereby reduced from 1% to about 0.3%. The excessive loss was due to the fact that there was not sufficient volatile matter in a sample to expel the 30 c.c. of air in the crucible when the heating was begun.

The Meker burner is superior to the Bunsen burner, especially for natural gas. The construction practically eliminates the fluctuating inner cone of the ordinary Bunsen flame, and thus affords a solid flame of fairly uniform temperature, which completely envelops the bottom and sides of the crucible.

Coal gas and water gas will readily produce a crucible temperature of 950° C. when supplied to a burner at a pressure of about 2 in. of water.

The *Bureau of Mines* found that with several samples of coal it was impossible to duplicate volatile matter determinations by the method of heating for seven minutes at 950° C., which is for convenience termed the "official method." It was found that there was a mechanical loss due to the throwing out of solid particles by the rapid expulsion of volatile matter and that there was a different breaking down of the hydrocarbons when expelled under different conditions and in the presence of variable amounts of moisture. A modified method was developed whereby the sample was given a preliminary heating for 4 minutes and then the regular 7-min. heating at full temperature.

The same coal was treated under both methods. That mechanical losses occurred during the rapid evolution of the volatile matter by the official method was indicated by the shower of solid carbon particles driven off as sparks. The average result of the official method was volatile matter 67.1%, ash 4.34%. For the modified method, volatile matter 36.35%, ash 11.15%. The moisture in the sample determined at this time was 19.78%, and the fixed carbon 32.72%. The difference in the ash report on the two tests was 6.81%, or the part of the ash driven off with carbon is 61%. Taking this proportion of the fixed carbon result by the modified method gives 20% as the amount of fixed carbon expelled mechanically in the official method. Correcting the result of the official method by this would show the following analysis: Moisture 19.78, volatile 47.10, fixed carbon 21.97, ash 11.15. The analysis by the modified method would show

moisture 19.78, volatile 36.35, fixed carbon 32.72. After making the correction for mechanical losses of fixed carbon, there is a difference of 10.75% between the two processes of determining volatile. This must be due to the difference in the breaking down of the hydrocarbon compounds by the different treatments.

Results show, at least for lignite, that the fineness of the sample has an important effect upon the volatile determination. The finer the particles the less the volatile showing. Tests on bituminous coals showed somewhat lower volatile results for the finer particles. This is probably due to the more complete sintering together of the fine samples on heating, with a consequent effect on the giving off of volatile.

When coals ranging from peat to anthracite were tested, and the volatile matter found both by the official and the modified method, it was found, with the exception of anthracite and semi-anthracite samples, that the results by the modified method all showed a considerably smaller amount of volatile matter and a correspondingly greater amount of fixed carbon. In all but the lignite the ash contents were about the same when the two methods were used, so that the difference is due to the breaking down of the hydrocarbons.

Air-dried coals were mixed with known amounts of water to ascertain what effect loosely-held moisture has on the volatile determination. By both methods the volatile indicated was greater with the coals moistened. It appears that a rapid application of heat to drive off moisture results in a reaction between the water vapor and the carbon or hydrocarbon.

The conclusion is reached that the value obtained in the volatile determination is affected to an important degree by:

1 The method of heating;

2. The fineness of pulverization;

3. The amount of loosely-held moisture in the sample.

In bituminous coals these differences do not exceed 3 or 4%, and therefore the official method is used. In lignites the differences may run up to 25%, and so the modified method is used by the *Bureau of Mines*.

Determination of Ash.—*A.S.T.M., A C.S., and A.S.M.E.* method D22-24. Apparatus required:

Gas or Electric Muffle Furnace.—The muffle should have good air circulation and be capable of having its temperature regulated between 700 and 750° C.

Porcelain Capsules.—Porcelain capsules, ⅞ in. deep and 1¾ in. in diameter, or similar shallow dishes.

Place the porcelain capsules containing the dried coal from the moisture determination in a cold muffle furnace, or on the hearth at a low temperature, and gradually heat to redness at such a rate as to avoid mechanical loss from too rapid expulsion of volatile matter. Finish the ignition to constant weight (± 0.001 g.) at a temperature between 700 and 750° C. Cool in a desiccator, and weigh as soon as cold. The permissible differences in duplicate determinations are as follows:

	Same Analyst	Different Analysts
No carbonates present	0.2%	0.3%
Carbonates present	0.3%	0.5%
Coals with more than 12% of ash, containing carbonates and pyrite	0.5%	1.0%

Before replacing the capsules in the muffle for ignition to constant weight, the ash should be stirred with a platinum or nichrome wire. Stirring once or twice before the first weighing hastens complete ignition. The result obtained by this method is "uncorrected" ash. For "corrected" ash see the preliminary report 1914.[1] The actual mineral matters in the original coal are usually very different in weight and composition from the weight of the "uncorrected" ash.

For technical purposes the uncorrected ash is reported as determined. The principal use of corrected ash values is in computing the actual coal substance or combustible matter of coal, for comparing ultimate analyses and heating values on this basis. Coal may contain calcium carbonate, iron carbonate or iron pyrites. These, together with the water of composition of the mineral substances, would be altered in composition by the ash determination as done above. *Parr* has suggested a method of correcting for these errors. At best the corrections are only approximations, and since the errors are small, they need not be considered in ordinary practice.

Determination of Fixed Carbon.—Compute fixed carbon as follows:

$$100 - (\text{moisture} + \text{ash} + \text{volatile matter}) = \text{percentage of fixed carbon}$$

The fixed carbon does not represent all of the carbon in the coal, as a considerable part of the carbon will have been driven off in the volatile hydrocarbon. Neither is the fixed carbon pure carbon. In addition to some ash-forming constituents, it contains several tenths per cent. of hydrogen and oxygen, 0.4 to 1% of nitrogen and approximately half of the sulphur in the coal.

Davis & Fairchild have investigated, by the method of least squares, the **probable error** of the various determinations necessary to a proximate analysis by comparing the variations from the mean of analyses of duplicate samples. The results are given below:

	Probable error %	Maximum error %
Effect of sampling on ash determination....	.04	.20
Ash determination	.08	.40
Moisture determination	.04	.20
Volatile matter determination..............	.15	.75
Calorimeter test	.15	.75
Calculated heat value........	.18	.90

The probable error is that whose probability is one-half—the chances being equal that the actual error is greater or less than it. The maximum error is that whose probability is 1 in 1000, and is about five times as great as the "probable" error. If two analyses of the same coal differ by more than this maximum error, a third analysis should be made.

Sulphur Determination.—Sulphur is often determined as a special item in connection with a proximate analysis, in addition to the four items totaling 100%. It occurs in coal in three forms·

1. As pyrite. This is its most common form in coal, and varies greatly in amount. In some coals the pyrite can be removed by picking or washing.

2. As sulphate of iron, calcium or aluminum. It may be found in this form in weathered coals. On exposure, pyrite tends to absorb oxygen and to form sulphate. Sulphur as sulphate has no heating value.

3. In combination with coal substances of organic composition. This form is next to pyrite in prominence. Little is known about it.

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[1]Report on Fixed Carbon and Ash, *Proceedings,* Am. Soc. Testing Mats., Vol. XIV, Part I, p. 426 (1914).

Sulphur in the free state has been found in coal in rare instances.

Iron pyrite is heavy, crystalline and brass-like in color. Calcium sulphate or gypsum occurs in small, thin white flakes, more or less transparent.

If the ash contains no lime or alkali oxides, sulphur is distributed about half in the volatile and half in the fixed carbon.

Determination of Sulphur by the Eschka Method —*A S.T.M., A.C.S.* and *A.S.M.E.* method D22-24. Apparatus required ·

Gas or Electric Muffle Furnace, or Burners —For igniting coal with the Eschka mixture and for igniting the $BaSO_4$.

Porcelain, Silica, or Platinum Crucibles or Capsules —Porcelain capsules, ⅞ in. deep and 1¾ in. in diameter, or porcelain crucibles of 30 c c capacity, high or low form, or platinum crucibles of similar size are to be used for igniting coal with the Eschka mixture

Porcelain, platinum, alundum, or silica crucibles of 10 to 15 c c. capacity, are to be used for igniting the $BaSO_4$

Barium Chloride —Dissolve 100 g of $BaCl_2·2H_2O$ in 1000 c c of distilled water.

Saturated Bromine Water —Add an excess of bromine to 1000 c c of distilled water.

Eschka Mixture —Thoroughly mix 2 parts (by weight) of light calcined MgO and 1 part of anhydrous Na_2CO_3. Both materials should be as free as possible from sulphur

Methyl Orange —Dissolve 0 02 g in 100 c c of hot distilled water and filter

Hydrochloric Acid —Mix 500 c c of HCl. sp. gr. 1 20, and 500 c c. of distilled water

Normal Hydrochloric Acid —Dilute 80 c.c of HCl, sp gr. 1 20, to 1 liter with distilled water

Sodium Carbonate —A saturated solution, approximately 60 g of crystallized or 22 g. of anhydrous Na_2CO_3 in 100 c c of distilled water

Sodium-Hydroxide Solution – Dissolve 100 g in 1 liter of distilled water. This solution may be used in place of the Na_2CO_3 solution

Thoroughly mix 1 g. of coal and 3 g. of Eschka mixture. Transfer to a porcelain capsule, ⅞ in deep and 1¾ in. in diameter, or a porcelain crucible of 30 c c. capacity, high or low form, or platinum crucible of similar size, and cover with about 1 g. of Eschka mixture. On account of the amount of sulphur contained in artificial gas, the crucible shall be heated over an alcohol, gasoline or natural gas flame as in procedure (*a*) below, or in a gas or electrically heated muffle, as in procedure (*b*) below. The use of artificial gas for heating the coal and Eschka mixture is permissible only when the crucibles are heated in a muffle.

(*a*) Heat the crucible, placed in a slanting position on a triangle, over a very low flame to avoid rapid expulsion of the volatile matter, which tends to prevent complete absorption of the products of combustion of the sulphur. Heat the crucible slowly for 30 min., gradually increasing the temperature and stirring after all black particles have disappeared. which is an indication of the completeness of the procedure.

(*b*) Place the crucible in a cold muffle and gradually raise the temperature to 870-925° C. (cherry-red heat) in about 1 hr. Maintain the maximum temperature for about 1½-hr. and then allow the crucible to cool in the muffle. Remove and empty the contents into a 200-c.c. beaker and digest with 100 c.c. of hot water for ½ to ¾ hr., with occasional stirring. Filter and wash the insoluble matter by decantation. After several washings in this manner, transfer the insoluble matter to the filter and wash five times, keeping the mixture well agitated. Treat the filtrate, amounting to about 250 c.c., with 10 to 20 c.c. of saturated

bromine water, make slightly acid with *HCl* and boil to expel the liberated bromine. Make just neutral to methyl orange with *NaOH* or *Na₂CO₃* solution, then add 1 c.c. of normal *HCl*. Boil again and add slowly from a pipette, with constant stirring, 10 c.c. of a 10% solution of *BaCl₂ 2H₂O*. Continue boiling for 15 min. and allow to stand for at least 2 hr., or preferably over night, at a temperature just below boiling. Filter through an ashless filter paper and wash with hot distilled water until an *AgNO₃* solution shows no precipitate with a drop of the filtrate. Place the wet filter containing the precipitate of *BaSO₄* in a weighed platinum, porcelain, silica or alundum crucible, allowing a free access of air by folding the paper over the precipitate loosely to prevent spattering. Smoke the paper off gradually and at no time allow it to burn with flame. After the paper is practically consumed, raise the temperature to approximately 925° C. and heat to constant weight. The residue of *MgO*, etc., after leaching, should be dissolved in *HCl* and tested with great care for sulphur. When an appreciable amount is found this should be determined quantitatively. The amount of sulphur retained is by no means a negligible quantity.

In all cases a correction must be applied either (1) by running a blank exactly as described above, using the same amount of all reagents that were employed in the regular determination, or more surely (2) by determining a known amount of sulphate added to a solution of the reagents after these have been put through the prescribed series of operations. If this latter procedure is adopted and carried out, say, once a week or whenever a new supply of reagent must be used, and for a series of solutions covering the range of sulphur content likely to be met with in coals, it is only necessary to add to or subtract from the weight of *BaSO₄* obtained from a coal, whatever deficiency or excess may have been found in the appropriate "check" in order to obtain a result that is more certain to be correct than if a "blank" correction as determined by the former procedure is applied. This is due to the fact that the solubility error for *BaSO₄*, for the amounts of sulphur in question and the conditions of precipitation prescribed, is probably the largest one to be considered. *BaSO₄* is soluble in acids and even in pure water, and the solubility limit is reached almost immediately on contact with the solvent. Hence, in the event of using reagents of very superior quality or of exercising more than ordinary precautions, there may be no apparent "blank" because the solubility limit of the solution for *BaSO₄* has not been reached or at any rate not exceeded. As shown in the preliminary report, the Atkinson and sodium-peroxide methods give results in close agreement with the Eschka method. *Register* has shown that if 5% of nitrogen is present in the gases contained in the bomb calorimeter the sulphur of a coal is almost completely oxidized to *H₂SO₄* and the washings of the calorimeter may be used for the determination of sulphur.

The permissible differences in duplicate determinations are as follows:

	Same Analyst	Different Analysts
Sulphur under 2%	0 05%	0.10%
Sulphur over 2%.................	0.10%	0.20%

ULTIMATE ANALYSIS

An ultimate analysis does not distinguish between the carbon and hydrogen derived from the organic or combustible matter of the coal and the small proportion of these elements that may be present in an incombustible form in the mineral impurities. A correction is not necessary, as the error is small.

The proposed *A. S. M. E. Test Code* states that the ultimate analysis report shall contain the percentages by weight of the following constituents, Moisture, Carbon, Hydrogen, Oxygen, Nitrogen, Sulphur, Ash, on the "as received" or "as used" basis, with a second column giving the analysis on the dry basis.

EXAMPLE OF ULTIMATE ANALYSIS

	As Received	Dry Basis
Moisture	3.50%	....
Carbon	76.80	79.58%
Hydrogen	4.45	4.62
Oxygen	4.00	4.14
Nitrogen 1.40	1.40	1.45
Sulphur	1.65	1.71
Ash	8.20	8.50
	100.00	100.00

Carbon and Hydrogen Determination.—In the Standard Method D22-24 of the *A. S. T. M., A. C. M.* and *A. S. M. E*, the determination of carbon and hydrogen is made with a weighed quantity of sample in a 25-burner combustion furnace of the Glaser type. The products of combustion are thoroughly oxidized by being passed over red-hot CuO and $PbCrO_4$ and are fixed by absorbing the water in a weighed Marchand tube filled with granular $CaCl_2$ and by absorbing the CO_2 in a Liebig bulb containing a 30% solution of KOH.

The apparatus used consists of a purifying train, in duplicate, a combustion tube in the furnace, and an absorption train. The purifying train consists of the following purifying reagents arranged in order of passage of air and oxygen through them: H_2SO_4, KOH solution, soda lime, and granular $CaCl_2$. One of the trains is for air and one for oxygen. In the H_2SO_4 and KOH scrubbing bottles the air and the oxygen are made to bubble through about 5 mm of the purifying reagent. Both purifying trains are connected to the combustion tube by a Y-tube, the joint being made tight by a rubber stopper.

The combustion tube is made of hard Jena glass. Its external diameter is about 21 mm, and its total length is 1 meter. The first 30 cm. of the tube are empty; following this empty space is an asbestos plug (acid washed and ignited) or in its place a roll of oxidized copper gauze may be used; the next 40 cm. are filled with "wire" CuO, a second asbestos plug separates the copper oxide from 10 cm. of fused $PbCrO_4$, which is held in place by another asbestos plug 20 cm from the end of the tube. The end of the tube is drawn out for rubber-tubing connection with the absorption train. The absorption train consists, first, of a Marchand tube filled with granular $CaCl_2$ to absorb moisture. The $CaCl_2$ should be saturated with CO_2 before using. The Marchand tube is followed by a Liebig bulb containing a 30% KOH solution, in which any possible impurities, as ferrous iron or nitrites, have been oxidized by a little $KMnO_4$. A guard tube, containing granular $CaCl_2$ and soda lime, is attached to the Liebig bulb to absorb any CO_2 escaping the KOH solution and any water evaporating from that solution. The train is connected to an aspirator which draws the products of combustion through the entire train. A guard tube of $CaCl_2$ prevents moisture from running back into the absorption train. The suction is maintained constant by a Mariotte flask. The advantage of aspirating the gases through the train rather than forcing them through by pressure is that the pressure on the rubber connections is from the outside, so that gas-tight connections are more easily maintained than if the pressure is on the inside of the tube. The connections are made as tight as possible. The usual test for tightness is to start aspiration at the rate of about three bubbles of air per second through the potash bulb, and then to close the inlet for air and oxygen at the opposite end of the train; if there is no more than one bubble per minute in the potash bulb, the apparatus is considered tight.

Before starting a determination when the train has been idle some hours, or after any changes in chemicals or connections, a blank is run by aspirating about 1 liter of air through the train, which is heated in the same manner as if a determination on coal were being made. If the Liebig bulb and the tube containing calcium chloride show a change in weight of less than 0.5 mg. each, the apparatus is in proper condition for use. A porcelain or platinum boat is provided with a glass weighing tube of suitable size, which is fitted with an accurately ground glass stopper.

The tube and empty boat are weighed. Approximately 0.2 g. of the air-dry coal (passing a No. 60 sieve and finer, or better, passing a No. 100 sieve if much impurity is present) are quickly placed in the boat. The boat is at once placed in the weighing tube, which is quickly stoppered to prevent moisture change in the coal while weighing and transferring to the furnace. The absorption tubes are connected and the boat and sample are transferred from the weighing tube to the combustion tube, which should be cool for the first 30 cm. The CuO should be red hot and the $PbCrO_4$ at a dull-red heat. The transfer of the boat from weighing tube to combustion tube should be made as rapidly as possible. As soon as the boat is in place near the asbestos plug at the beginning of the copper oxide the stopper connecting with the purifying train is inserted and the aspiration started with pure oxygen gas at the rate of three bubbles per second. One burner is turned on about 10 cm. back from the boat, and the aspiration is continued carefully until practically all the moisture is expelled from the sample. The heat is then increased very gradually until all the volatile matter has been driven off. In driving off the volatile matter the heat must be applied gradually in order to prevent a too rapid evolution of gas and tar, which may either escape complete combustion or may be driven back into the purifying train. The heat should be slowly increased by turning on more burners under the open part of the tube until the sample is ignited; then the temperature can be increased rapidly, but care should be taken not to melt the combustion tube. Any moisture collecting in the end of the combustion tube or in the rubber connection joining it to the $CaCl_2$ tube is driven over into the $CaCl_2$ tube by carefully warming with a piece of hot tile. The aspiration with oxygen is continued for 2 min. after the sample ceases to glow, the heat is then turned off and about 1200 c.c. of air are aspirated. The absorption bulbs are then disconnected, wiped with a clean cloth, and allowed to cool to the balance-room temperature before weighing.

$$\text{Percentage of hydrogen} = \frac{11.19 \times (\text{increase in weight of } CaCl_2 \text{ tube})}{\text{Weight of sample}}$$

$$\text{Percentage of carbon} = \frac{27.27 \times (\text{increase in weight of } KOH \text{ bulb})}{\text{Weight of sample}}$$

The ash in the boat is weighed and carefully inspected for any unburned carbon, which would destroy the value of the determination.

Method with Electrically Heated Combustion Furnace.—An electrically heated combustion furnace of the Heraeus type is used by the Bureau of Mines. It consists of three independent heaters, two of which are provided with sheave wheels, and are mounted on a track so that they are movable along the tube; the third heater which surrounds the $PbCrO_4$, is stationary. The furnace as provided by the manufacturer does not include the small stationary heater. This can be made in the laboratory by winding an alundum tube 12 cm. in length with No. 20 nichrome II wire and enclosing it in a cylinder packed with magnesia-asbestos. The movable heaters have very thin platinum foil, weighing about 9 g. in all, wound on a porcelain tube of 30 mm. internal diameter. The larger one, which heats the CuO, is 350 mm. in length, and the smaller one, which heats the sample in the boat, is 200 mm. in length. The Jena glass or fused silica combustion tube, of about 21 mm. external diameter and 900 mm. in length, is supported by an asbestos-lined nickel trough. The current through each heater is regulated independently by separate rheostats mounted on the frame of the furnace. The two platinum-wound heaters require an average current of about 4.5 amperes at a pressure of 220 volts, although for heating rapidly a larger amperage is necessary.

The oxygen or air entering the combustion tube is purified by passing through a Tauber's drying apparatus, which contains the following reagents arranged in order of the passage of air or oxygen through them: H_2SO_4, for removing possible traces of ammonia, 30% KOH solution, granular, soda lime, and granular $CaCl_2$. One side of the train is connected directly to a Linde oxygen tank, which is provided with a reducing valve for regulating the oxygen pressure, the other side of the train is used for purifying the air supply. The absorption train consists of a 5-in. U-tube, filled with granular $CaCl_2$ to absorb moisture. Before using, the $CaCl_2$ should be saturated with CO_2 to avoid possible absorption of CO_2 during a determination by any traces of CaO that may be present. This saturating is done most conveniently by placing a quantity of $CaCl_2$ in a large drying jar, and filling the jar with CO_2. After standing over night, dry air is drawn through the jar to remove the CO_2. The treated $CaCl_2$ is kept in well-stoppered bottles. The $CaCl_2$ tube is connected to a Vanier potash bulb containing a 30% KOH solution and granular $CaCl_2$. Six to eight determinations can be made without recharging this bulb. The potash bulb is connected to an aspirator through a guard tube containing granular $CaCl_2$ and soda lime, and a Mariotte flask. The Mariotte flask keeps the pressure constant.

In general, the method of determination is the same as the one used with the gas furnace. By moving the heaters toward the end of the tube where the gases enter, and cutting in the electric current, the air can be warmed enough to thoroughly dry the tube and its contents. The current is then cut off from the small heater, and the large heater is moved over the CuO; about 250 mm. of that part of the combustion tube between the two heaters where the boat containing the sample is to be placed is kept exposed. The full current is then turned on the large heater to bring the CuO to a red heat. When this temperature is reached it is necessary to reduce the current with a rheostat to avoid melting the tube. In the meantime the absorption train is weighed and connected, and the boat containing the sample is placed in the exposed and cooler part of the tube between the two heaters. The current is then passed through the shorter heater. By manipulating the rheostat and by gradually pushing this heater toward the boat, the rate of evaporation of moisture and evolution of volatile matter can be readily controlled.

After combustion is complete, the electric current is turned off the smaller heater and this heater moved back to allow the tube to cool for the next determination. The final aspiration of air and the weighing of the absorption train is conducted as described under the gas-furnace method.

In place of granulated $CaCl_2$, concentrated H_2SO_4 may be used for collecting the water formed by combustion. In such cases the air and oxygen entering the combustion tube and the gas leaving the potash bulb must also be dried by H_2SO_4. Other suitable forms of absorption vessels than those indicated in the above procedure may be used.

Nitrogen Determination.—The Kjeldahl-Gunning method is recommended by the A. S. T. M., A. C. M. and A. S M E. for the determination of nitrogen. This method has the advantage over either the simple Kjeldahl or the Gunning method, in requiring less time for the complete oxidation of the organic matter, and in giving the most uniform results. One gram of the coal sample is boiled with 30 c.c. of concentrated H_2SO_4, 7 to 10 g. of K_2SO_4, and 0.6 to 0.8 g. of metallic mercury in a 500-c.c. Kjeldahl flask until all particles of coal are oxidized and the solution nearly colorless. The boiling should be continued at least 2 hr. after the solution has reached the straw-colored stage. The total time of digestion will be from 3 to 4 hr. The addition of a few crystals of $KMnO_4$ after the solution has cooled enough to avoid violent reaction tends to insure

complete oxidation. After cooling, the solution is diluted to about 200 c.c. with cold water. If the dilution with water has warmed the solution, it should be again cooled and the following reagents added: 25 c.c. K_2S solution (40 g. K_2S per liter) to precipitate the mercury; 1 to 2 g. of granular zinc to prevent bumping; and finally enough strong $NaOH$ solution (usually 80 to 100 c.c.) to make the solution distinctly alkaline. The danger of loss of NH_3 may be minimized by holding the flask in an inclined position while the $NaOH$ solution is being added. The alkaline solution runs down the side of the flask and forms a layer below the lighter acid solution. After adding the alkaline solution, the flask is at once connected to the condensing apparatus and the solution mixed by gently shaking the flask. The NH_3 is distilled over into a measured amount (10 c.c.) of standard H_2SO_4 solution, to which has been added sufficient cochineal indicator for titration. Care should be taken that the glass connecting tube on the end of the condenser dips under the surface of the standard acid. The solution is slowly distilled until 150 to 200 c.c. of distillate has passed over. To avoid mechanically entrained alkali passing over into the condenser, the rate of distillation should not exceed 100 c.c. per hour. The distillate is titrated with standard NH_3 solution (20 c.c. NH_4OH solution $= 10$ c.c. H_2SO_4 solution $= 0.05$ g. nitrogen). Standard $NaOH$ or KOH solution with methyl orange or methyl red as indicator may be used instead of NH_3 and cochineal.

A blank determination should be made in exactly the same manner as described above, except that 1 g. of pure sucrose (cane sugar) is substituted in place of the coal sample. The nitrogen found in this blank determination is deducted from the result obtained with the coal sample. The K_2S and $NaOH$ may be dissolved in a single stock solution. Sufficient K_2S is dissolved in the water before adding the $NaOH$, to make a solution in which the quantity necessary for a nitrogen determination (80 to 100 c.c.) contains 1 g. of K_2S. Twelve grams of K_2S and 500 g. of $NaOH$ in one liter of water are required for the above proportions. Coke and anthracite should be ground to an impalpable powder, as they are very difficult to oxidize. Even if this is done the digestion may require 12 to 16 hours.

Moisture, Sulphur and Ash Determinations.—The moisture and sulphur determinations for the ultimate analysis are the same as described under proximate analysis, pages 35 and 40. The ash is found by weighing the refuse left in the combustion boat after the coal is completely burned.

Oxygen Determination.—There being no satisfactory direct method of determining oxygen, it is computed by subtracting the sum of the percentages of hydrogen, carbon, nitrogen, sulphur, water and ash from 100. The result so obtained is affected by all the errors incurred in the other determinations and especially by the change in weight of the ash-forming constituents on ignition; iron pyrite changes to ferric oxide, increasing the ash and causing a negative error in the oxygen equivalent to three-eighths of the pyritic sulphur. On the other hand, there is always a loss on ignition, of water of composition from the clayey and shaley constituents, CO_2 from carbonates, etc., which tends to compensate the absorption of oxygen.

Corrected Oxygen.—When a more correct oxygen value is desired, it may be obtained by making the corrections indicated in the following formula of the *A.S.T.M.:*

Corrected oxygen = 100 — [$(C — C')$ + $(H — H')$ + N + H_2O + S' + corrected ash], in which

C = total carbon,
C' = carbon of carbonates,
H = total hydrogen less hydrogen of water,
H' = hydrogen from water of composition in clay, shale, etc.,
N = nitrogen.
H_2O = moisture as found at 105° C,
S' = sulphur not present as pyrite or sulphate   This is usually small   In many types of coal it may be disregarded.
Corrected ash = mineral constituents originally present in the coal For most pur poses this can be determined with sufficient accuracy by adding to the ash, as found, five-eighths of the weight of pyritic sulphur the CO_2 of carbonates and the water of composition of clay, shale, etc See also ash determination, p. 39.

The assumption that all of the oxygen in the coal is combined with ⅛ of its weight of hydrogen as water is well supported in anthracite and bituminous coals by the agreement of the heat value computed by DuLong's formula with the actual bomb calorimeter determination. The remainder of the hydrogen is termed "available hydrogen."

Applications.— The ultimate analysis is useful for classifying a coal or predicting its performance (p 5)   It is also necessary in making an itemized heat balance in boiler testing.   Approximate calculations of heating values are sometimes made from ultimate analyses (see p 58).   The ultimate analysis of coal requires the use of so much chemical apparatus, and at best is so complicated that it is not likely to be done except in a fully equipped laboratory.

Total Carbon and Hydrogen from Proximate Analysis.—*F A. Shorkey* gives the accompanying charts for estimating the hydrogen and carbon from proximate analyses. If the fixed carbon is 65% and the volatile matter 27%, dry-fuel basis, the total combustible in dry fuel is $65 + 27 = 92\%$, and the volatile in the combustible is 27/92, or 29 3%. Entering chart *A* at 29 3 on the left, following to the dotted line and up to the 92% curve, gives 4.73% hydrogen in dry fuel. Similarly, Fig. *B* gives 14.5% volatile carbon in the fuel; total carbon $= 65 + 14 5 = 79 5\%$.
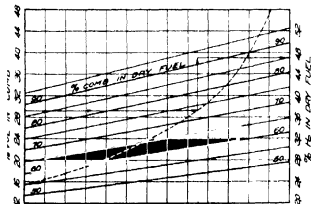
A. ESTIMATION OF HYDROGEN
FROM PROXIMATE ANALYSIS
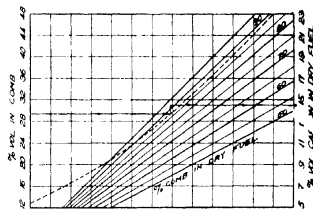
B. ESTIMATION OF VOLATILE
CARBON FROM PROXIMATE
ANALYSIS
—*Blast Furnace & Steel Plant.*

A. ESTIMATION OF HYDROGEN
   FROM VOLATILE MATTER

B. RELATION OF CARBON AND
   ASH TO SPECIFIC GRAVITY OF
   ANTHRACITE.
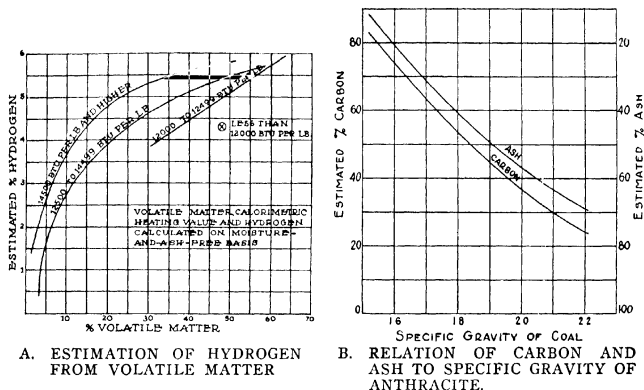
The *Bureau of Mines* gives the data in Fig. A, compiled by *A. C. Fieldner* and *W. A. Selvig*, for estimating hydrogen from the volatile, calculated on the moisture-and-ash-free basis. The coals and lignites are grouped by calorimetric heating values.

Frederic C. Evans gives the following empirical formulas for estimating carbon and hydrogen:

Pa., O., W. Va., Md., Va., Ky., Ga., Tenn., Ala.:
$C = 0.943 - 0.242V$, for $V < 0.36$
$C = 1.095 - 0.663V$, for $V > 0.36$

Ill., Ind., Mich., Ia., Neb., Kan., Mo., Okla., Ark., Tex.:
$C = 0.953 - 0.362V$, for all values of V

Col., Utah, N. M., Ariz., Wyo., Mont., Wash., Ore., Cal., for $0.36 < V < 0.60$:
$C = (H.V. + 7544) \times (.0099 + .0208V) \div (737.5V + 200)$

All states, for $V > 0.60$·
$C = (H.V. + 7544) \times (.0099 - .0045V) \div (11.3V + 200)$

All states but Ark.:
$H = 0.013 + 0.225V$, for $.04 < V < 0.16$
$H = 0.0457 + 0.0206V$, for $0.16 < V$

For Ark. coals:
$H = 0.0327 + 0.056V$

$H.V. =$ Htg. value of combustible (moisture and ash free) *BTU* per lb., see p. 57.
$V =$ fraction of volatile matter in combustible
$C =$ fraction of total carbon in combustible
$H =$ fraction of hydrogen in combustible
Formulas do not cover lignites, wood, etc.

The ash and carbon content of anthracite coal can be estimated by means of Fig. B, due to *Hachita*.

Probable Ultimate Analysis from Proximate Analysis.—The following formulas, derived by *J. P. Calderwood,* can be used for estimating the probable ultimate analysis of a coal from the proximate, provided the latter includes the heat value and the sulphur content.

Probable
error %

$$C = .00512(BTU - 40.5S) + 0053[80 - (100VM/FC)]^{1\ 540} + 5.88 \qquad 0.274$$

$$O = (8/9)M + \{ D - 07\sqrt{[1 - .05(D - 9.5)^2]} \}^{1\ 78} - 13.93, \text{ for } D < 14 \qquad 0.699$$

$$\quad = (8/9)M + \{ D + 07\sqrt{[1 - .05(D - 18.5)^2]} \}^{1\ 78} - 13.93, \text{ for } D > 14 \qquad 0.699$$

$$H = 1.02 \ (D - S - O) + 1.018M - 1.65 \qquad 0.383$$

$$N = D + M - S - O - H \qquad 0.428$$

wherein C, O, H, and N equal estimated chemical content of carbon, oxygen, hydrogen and nitrogen in the coal, expressed as % of air-dried coal;

$BTU = BTU$ per lb. air-dried coal
$\quad S = $ sulphur as reported, % of air-dried coal
$VM = $ volatile matter as reported, % of air-dried coal
$FC = $ fixed carbon as reported, % of air-dried coal
$\quad M = $ moisture as reported, % of air-dried coal
$\quad D = FC + VM - C$

The four quantities thus estimated, with the S and Ash already determined, should total 100%, and they can be adjusted to meet this requirement by the following formulas, in which allowance is made for the probable error in each ·

$$C_c = C(1 + 0.15d), \ O_c = O(1 + 0.40d),$$
$$H_c = H(1 + 0.21d), N_c = N(1 + 0.24d)$$

wherein $d = 100 - (C + O + H + N + S + \text{Ash})$, and may be positive or negative, being in the neighborhood of 1%.

In the final corrected estimates compared with actual ultimate analyses, the errors in the separate constituents were in general less than ½%, and never exceeded 2%, even for oxygen.

In applying these figures to boiler tests requiring the use of ultimate analysis data, the probable error in theoretical air supply is 1.4%, in actual air 0.986%, and excess air 0.175%, while that in the heat balance is 8 *BTU*. These errors are less than others inevitable in such tests.

HEATING VALUE

The heating value, or calorific value, of a coal is the number of units of heat liberated by the perfect combustion of one unit weight of the coal.

A British Thermal Unit (*BTU*) is the quantity of heat required to raise the temperature of 1 lb. of water 1° F. (to be exact, from 63° to 64° F.).

The gram calorie (small calorie) is the quantity of heat required to raise the temperature of 1 gram of water 1° C. at a mean temperature of 15° C.

The kilogram calorie (large calorie) is 1000 times the small calorie. It is equal to *3.968 BTU.*

The necessity of knowing the heating value of the coal burned can be seen when we consider that the evaporation per pound of coal burned does not of itself indicate efficiency. An equivalent evaporation of 8 lb. of water per pound of dry coal could represent 70½% efficiency if the coal contained 11,000 *BTU* per lb., but the same evaporation with a coal of 14,500 *BTU* heating value would represent only 53½% efficiency.

While the determination of the heat value does not give all the information desirable as to quality of a fuel, it is more valuable than any other single laboratory test, as it reflects the heat content which will be available in actual combustion. For this reason the Government and many other large consumers are purchasing fuel under specifications based on heating value. The cost of calorimetric determinations must, of course, be kept within the limits dictated by their economic value. The statement is sometimes made that an accuracy within 1% is sufficient, as the errors of sampling may be this great, but sampling errors affect principally the ash and moisture content, and calorimeter reports with an accuracy within 0.1 to 0.2% have therefore a practical value when corrected to an ash-and-moisture-free basis.

Two heating values are recognized for fuels containing hydrogen. In the calorimeter the water formed by the combustion of the hydrogen is condensed, and gives up its heat to the water-jacket, whereas under boiler conditions the gases formed escape at temperatures well above the boiling point of water, and the latent heat required for the vaporization of the water is therefore carried off and is unavailable A "lower heating value" is often calculated, in which allowance is made for this inevitable loss of heat, but it is an artificial unit, involving reference to the ultimate analysis and other complicated assumptions, while the higher value, as given by the calorimeter, is a scientific unit, and its use is recommended by the *American Society of Mechanical Engineers.*

For oils, the low heating value is often calculated by deducting 8730*H* from the calorimeter report, where *H* is the fraction of hydrogen in the fuel. The *A.S.T.M.* defines the "net heat of combustion at 20° C" (68° F.) as the heat developed on complete combustion of a unit weight of fuel with the water in the products of combustion passing off as vapor at 20° C. In *BTU* per lb., it equals the "total" or calorimeter heat of combustion minus 9360*H* If *H* has not been determined, it can be estimated by the method of p. 48.

A calorimeter is essentially an instrument for securing practically complete combustion of a representative weighed sample of the fuel under investigation, and for measuring the heat generated, by the increase in temperature of the water jacket and of the calorimeter parts. The favored type is the bomb calorimeter, in which a small sample of the coal is placed in a cylindrical bomb 2 to 3 in. in diameter, in contact with oxygen under several hundred pounds pressure, and the whole sealed and ignited electrically, when immersed in a water bath under known conditions.

The requirements for a combustion calorimeter are as follows:

(*a*) That it shall effect complete combustion;
(*b*) That it shall allow no heat to escape absorption by the water;

(c) That its radiation and absorption factor shall be as small as possible, thus making the correction small;

(d) That the thermometer used for measuring the temperature difference shall be of the best quality and carefully calibrated

Calorimetric Determination.—The Standard Method D22-24 of the *A. S. T. M.* and the *A. C. S.* calls for the following apparatus:

Combustion Bombs—The Atwater, Davis Emerson Mahler Parr, Peters, Williams, or similar bombs may be used. The bomb shall have an inner surface of platinum, gold, porcelain enamel, or other material which is not attacked by HNO_3 and H_2SO_4, or other products of combustion.

Calorimeter Jacket—The calorimeter must be provided with a water-jacket having a cover to protect the calorimeter from air currents The jacket must be kept filled with water within 2 or 3° C. of the temperature of the room (except in calorimeters which are totally submerged where the jacket temperature is controlled by a thermostat) and should be stirred continuously by some mechanical stirring device.

Stirring of the Calorimeter Water—The water in the calorimeter must be stirred sufficiently well to give consistent thermometer readings while the temperature is rising rapidly. The speed of stirring should be kept constant A motor-driven screw or turbine stirrer is recommended and the speed should not be excessive This may be determined by adjusting the temperature of the calorimeter to equality with that of the jacket and allowing the stirrer to run continuously for ten minutes If the temperature of the calorimeter rises more than about 0 01° C in this length of time the rate of stirring is excessive. Accurate results cannot be obtained when too much energy is supplied by the stirring device or when the rate of stirring is irregular The portion of the stirring device immersed in the calorimeter should be separated from that outside by non-conducting material, such as hard rubber, to prevent conduction of heat from the motor or outside air.

Thermometers—Thermometers used shall have been certified by a government testing bureau and shall be used with the corrections given on the certificate. This shall also apply to electrical resistance of thermo-electric thermometers Correction shall also be made for the temperature of the emergent stem of all mercurial thermometers, and for the "setting" of Beckmann thermometers For accurate work either Beckmann or special calorimetric thermometers graduated to 0 01 or 0 02° C. are required Such thermometers should be tapped lightly just before each reading to avoid errors caused by the sticking of the mercury meniscus, particularly when the temperature is falling A convenient method is to mount a small electric buzzer directly on the top of the thermometer and connect it up with a dry cell and a push button The button should be pressed for a few seconds immediately before each reading

Oxygen—The oxygen used for combustions shall be free from combustible material The bomb when filled should contain at least 5% of nitrogen to insure complete oxidation of the sulphur. The total amount of oxygen contained in the bomb for a combustion shall not be less than 5 g per gram of coal But the combustion must be complete, as shown by the absence of any sooty deposit on opening the bomb after firing

Firing Wire—The coal in the bomb may be ignited by means of either iron or platinum wire. If iron is used, it should be of about No 34 B & S gage and not more than 10 cm (preferably 5 cm) should be used at a time A correction of 1600 calories per gram weight of iron wire burned is to be subtracted from the observed number of calories.

Standardization—The water equivalent of a calorimeter can best be determined by the use of the standard combustion samples supplied by the Bureau of Standards The required water equivalent is equal to the weight of the sample multiplied by its heat of combustion per gram and divided by the corrected rise in temperature. The calorimeter shall be standardized by the combustion of standard samples supplied by the Bureau of Standards, and used according to the directions given in the certificates

*The corresponding paragraph in the proposed *A. S M. E.* Code reads:

Only the oxygen bomb calorimeter such as the Mahler Atwater Emerson and Parr's Illium-Alloy Oxygen Bomb shall be considered as standard in determining the heating value of fuels Only calorimeter bombs which are non-corrosive or have a non-corrosive lining of platinum, gold, porcelain, or other metals not attacked by nitric and sulphuric acids or other products of combustion, may be used. The "high" heating value shall be used for solid fuels.

which accompany them   A standardization shall consist of a series of not less than five combustions of either the same or different standard materials   The conditions as to the amount of water, oxygen, firing wire, method of correcting for radiation, etc, under which these combustions are made shall be the same as for coal combustions   In the case of any disagreement between contracting parties a check standardization may consist of two or more combustions of standardizing samples

The ground sample is to be thoroughly mixed in the bottle and an amount, approximately 1 g, is to be taken out and weighed in the crucible in which it is to be burned   Coals which are likely to be blown out of the crucible should be briquetted. After weighing, the sample should preferably be immediately placed in the bomb and this closed   This procedure is necessary to avoid sublimation in the use of naphthalene for standardization   The firing wire, if iron, should be measured and coiled in a small spiral and connected between the platinum terminals, using, if necessary, a piece of platinum wire somewhat heavier than the iron wire, to make the connection.   The platinum and the iron must both be clean.   About 0.5 c c. of water should be placed in the bottom of the bomb to saturate with moisture the oxygen used for combustion.   When the crucible is put in place in the bomb, the firing wire should touch the coal or briquette of standard material   For the combustion of standardizing samples iron wire is preferable to platinum.   Oxygen from the supply tank is to be admitted slowly to avoid blowing the coal from the crucible, and the pressure allowed to reach 20 atmospheres for the larger bombs or about 30 atmospheres for the smaller bombs, so that the bomb shall contain an amount of oxygen sufficient for complete combustion, namely, at least 5 g. per gram of coal, or other combustible.   This method of filling will insure 4% of nitrogen in the larger bombs, irrespective of the nitrogen contained in the oxygen   The calorimeter is to be filled with the required amount of distilled water, depending upon the type of calorimeter.   The amount may be determined either by measurement in a standardized flask or by weighing.   The amount must be kept the same as that used in standardization of the apparatus.

The initial temperature in the calorimeter should be so adjusted that the final temperature, after the combustion, will not be more than 1° C., preferably about 0 5° C., above that of the jacket, under which conditions the total correction for heat gained from or lost to the surroundings will be small when the rise of temperature is 2 or 3° C and the effect of evaporation will also be small. The electric current used for firing the charge should be obtained from storage or dry cells having an electromotive force of not more than 12 volts, since a higher voltage is liable to cause an arc between the firing terminals, introducing additional heat, which cannot be measured with certainty   The circuit should be closed by means of a switch which should remain closed for not more than 2 sec. When possible, it is recommended that an ammeter be used in the firing circuit to indicate when the firing wire has burned out.

The bomb when ready for firing is to be placed in the calorimeter, the firing wires connected, the cover put in place, and the stirrer and thermometer so placed as not to be in contact with the bomb or container. The stirrer is then started and, after the thermometer reading has become steady, not less than 2 min. after the stirrer is started, temperatures are read at 1-min. intervals for 5 min. and the charge is then fired, the exact time of firing being noted. Observations of temperatures are then made at intervals depending upon the method to be used for computing the

cooling correction. When the temperature has reached its maximum and is falling uniformly, a series of thermometer readings is taken at 1-min. intervals for 5 min. to determine the final cooling rate. After a combustion the bomb is to be opened, after allowing the gas to escape, and the inside examined for traces of unburned material or sooty deposit. If these are found, the observations shall be discarded. If the combustion appears complete, the bomb is to be rinsed out thoroughly and the washings titrated with a standard alkali solution (1 c c. $= 0 02173$ g. $HNO_3 = 5$ calories) using methyl-orange or methyl-red indicator, to determine the amount of acid formed. A correction of 230 calories per gram of HNO_3 should be subtracted from the total heat observed An additional correction of 1300 calories per gram of sulphur in the coal should be made for the excess of difference in heats of formation of SO_2 and aqueous H_2SO_4 over the heat formation of aqueous HNO_3. The following method of computation is recommended to take the place of the Pfaundler or other similar formulas for computing the cooling correction (radiation correction).

Observe (1) the rate of rise (r_1) of the calorimeter temperature in degrees per min. for 5 min before firing; (2) the time (a) at which the last temperature reading s made immediately before firing; (3) the time (b) when the rise of temperature has reached six-tenths of its total amount (this point can generally be determined by adding to the temperature observed before firing, 60% of the expected[1] temperature rise, and noting the time when this point is reached); (4) the time (c) of a thermometer reading taken when the temperature change has become uniform some 5 minutes after firing, (5) the final rate of cooling (r_2) in degrees per minute for 5 minutes

The rate r_1 is to be multiplied by the time $b - a$ in minutes and tenths of a minute and this product added (subtracted if the temperature was *falling* at the ime a) to the thermometer reading taken at the time a. The rate r_2 is to be multiplied by the time $c - b$ and this product (subtracted if the temperature was *rising* at the time c and later) to the thermometer reading taken at the time c. The difference of the two thermometer readings thus corrected, provided the corrections from the certificate have already been applied, gives the total rise of temperature due to the combustion This multiplied by the water equivalent of the calorimeter gives the total amount of heat liberated This result, corrected for the heats of formation of HNO_3 and H_2SO_4 observed and for the heat of combustion of the firing wire, when that is included, is to be divided by the weight of the charge to ind the heat of combustion in calories per gram. Calories per gram multiplied by 1.8 give the British thermal units per pound. (See example, p. 54.)

The permissible differences in duplicate determinations are as follows:

	%
Same analyst	0.3
Different analysts	0.5

In practice, the time $b - a$ will be found so nearly constant for a given calorimeter with the usual amounts of fuel that b need be determined only occasionally. The results should be reduced to calories per gram or British thermal units per pound of *dry coal*, the moisture being determined upon a sample taken from the bottle at about the same time as the combustion sample is taken

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[1]When the temperature rise is not approximately known beforehand it is only necessary to take thermometer readings at 40, 50, 60 sec. (and possibly 70 sec. with some calorimeters) after firing, and from these observations to find when the temperature rise had reached 60% of the total. Thus, if the temperature at firing was 2.135°, at 40 sec. 3 05°, at 50 sec. 3.92°, at 60 sec 4 16°, and the final temperature was 4.200°, the total rise was 2.07°; 60% of it was 1 24°. The temperature to be observed was then 2.14° + 1.24° = 3.38°. Referring to the observations at 40 and 50 sec., the temperatures were respectively 3.05 and 3.92°. The time corresponding to the temperature of 3.38° was therefore

$$40 + \frac{3.38 - 3 05}{3.92 - 3.05} \times 10 = 44 \text{ sec.}$$

EXAMPLE

OBSERVATIONS

Water equivalent = 2550 g.   Weight of charge = 1.0535 g.   Approximate rise cf
temperature expected = 3.2°.   60% of approximate rise = 1.9°

Time.   Thermometer Readings   Corrected Temperature
(or corrected Beckmann thermometer readings).
10–21   15.244°   Thermometer corrections taken from the certificate.
22   .250
23   .255
24   .261
25   .266
(a) 26   .272   15.276°
                         Charge fired
(b) 27 2   17.2°*
31   18 500°   18 497°
32   .498
33   .497
34   .498
35   .494
36   .493

*The initial temperature is 15.27°; 60% of the expected rise is 1 9°. The reading
to observe is then 17.2°.

COMPUTATION

r_1 = 0 028° ÷ 5 = 0.0056° per min. $b - a$ = 1 2 min.
The corrected initial temperature is 15 276° + 0 0056° × 1.2 = 15.283°
r_2 = 0.007° ÷ 5 = 0.0014° per min.; $c - b$ = 3.8 min.
The corrected final temperature is 18 497° + 0 0014° × 3 8 .... = 18.502°
Total rise 18.502° — 15 283°......... .... = 3 219°
Total calories 2550 × 3.219...... . ... =   8209
Titration, etc. ....   — 7
                                                                                  ————
                                                                                  8202
Calories from 1.0535 g. coal...................... ....
Calories per gram..   7785
or British thermal units per pound........   14013

The result obtained by the above method of computation and determination is
the total heat of combustion at constant volume, with the water in the products of
combustion condensed to liquid at the temperature of the calorimeter, that is, about
20 to 35° C.   Net heat of combustion at 20°, shall refer to results corrected for latent
heat of vaporization, as follows: Total heat of combustion in BTU — 1040 (hydrogen
× 9) = net heat of combustion in BTU per lb.   Also, total heat of combustion in
calories — 580 (hydrogen × 9) = net heat of combustion in calories per gram.

For anthracite coke and coal of high ash content, which do not readily burn com-
pletely, the following procedure is recommended: The inside of the crucible is lined
completely with ignited asbestos in a thin layer pressed well down into the angles.
The coal is then sprinkled evenly over the surface of the asbestos.   Otherwise the pro-
cedure is as previously described.   The method of computing the "cooling correction"
described in *Technical Paper No. 8*, Bureau of Mines, pages 28 to 32, may also be
used.

One of the calorimeters used in the *Bureau of Mines* fuel inspection
laboratory is shown in the photograph, Fig. A.   The calorimeter has been
taken down to show its parts.   The platinum-lined steel bomb is shown open
at *a;* *b* is a cathotometer, magnifying power of about 55 diameters, used for
observing the thermometer, which is shown removed from the calorimeter
at *g.*   By means of this instrument the thermometer scale can be read accu-
rately to 0.001° C.   The calorimeter can *d*, containing exactly 1850 grains of
distilled water and the charged bomb, fits inside the double-walled felt-
lagged jacket *c;* *h* is a ball-stirrer of the propeller type driven at a constant
speed of 1800 rpm by means of a friction pulley and rubber band from the
shaft *i;* *f* is an electric thermometer tapper controlled by means of a push
button at the operator's table; *e* is a ½-HP. electric motor that runs at a
practically constant speed of 500 rpm.   This motor, belted to the shaft as
shown, serves to drive the stirrers of four calorimeters.
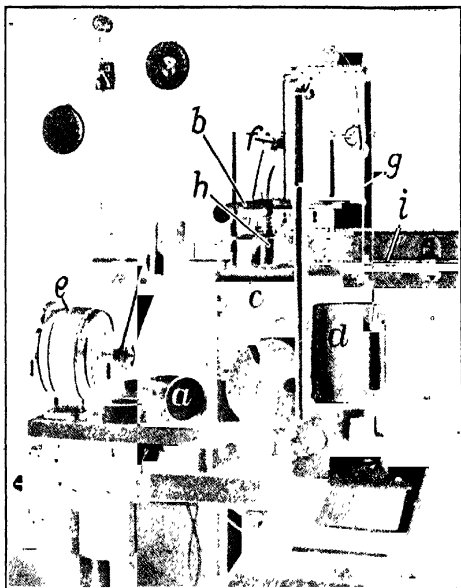
A. BOMB CALORIMETER DISMOUNTED TO SHOW PARTS

Special Calorimeter for Government Laboratory.—The *Bureau of Mines* has developed for its own use a multiple-unit calorimeter, Figure B, by which a skillful operator can average 35 determinations a day, the time consumed for a single actual observation being only 8 minutes. The probable error is 3.2 BTU in 14,600. The set consists of six units mounted on a constant-temperature tank containing water to a depth of 17 inches. The body and bottom piece of the bomb is made of monel metal, gold plated, with wiring connections through the bottom, and with a steel nut and lock at the top, which is sealed after inserting the sample and the oxygen under pressure. This has been found more satisfactory than the use of renewable shells, as both bomb and lock stand up for years under heavy service. The calorimeter can and jacket can are of heavy sheet brass, and when in use are immersed in the constant-temperature tank, with a water seal to prevent evaporation into the thin space between the two cans. The water in the large tank is kept in motion by a 9-inch propeller wheel at one end of a submerged tube extending the length of the tank, and is maintained at a temperature of 30° C. by a battery of lamps controlled
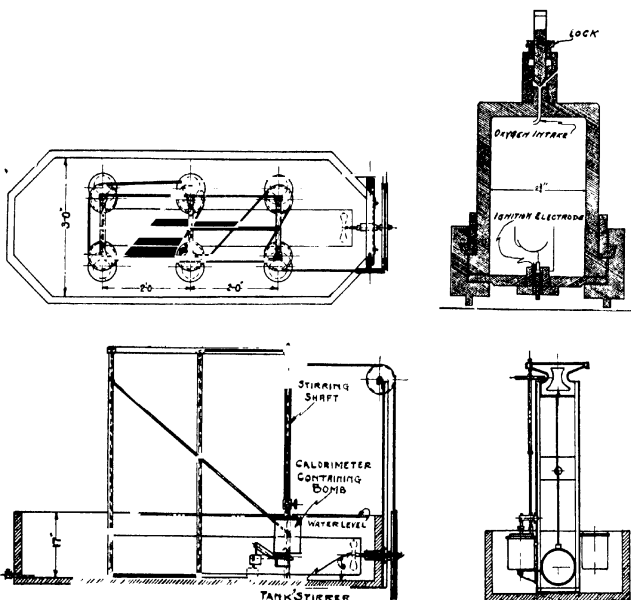
B. MULTIPLE-UNIT CALORIMETER INSTALLATION, WITH
SECTION OF BOMB USED

by a toluene thermostat. Measured quantities of water at known tempera-
tures for the calorimeters are taken from a supply tank, also under ther-
mostatic control, by automatic pipettes. Each calorimeter is stirred by a
1¼-in. wheel, running at 500 rpm, which does not augment the temperature
faster than .01° C. per minute.

Temperatures are measured by platinum resistance thermometers,
which obviate the troubles from lag, uneven bore and sticking in the bore
with mercury thermometers. These thermometers are read in connection
with a special Leeds & Northrup bridge and galvanometer, which can be
connected to any one of the calorimeters, and can be calibrated within
.001° C. The water equivalent of the calorimeter is ordinarily obtained by
burning a standard furnished by the *Bureau of Standards,* and noting the
temperature increment. The usual standard employed is a sample consist-
ing of 2 grams sucrose and .02 gram naphthalene, which produces 8107.3
calories, including that due to the formation of HNO_3, and the operation is
repeated six or eight times to secure an accurate value of the calorimeter
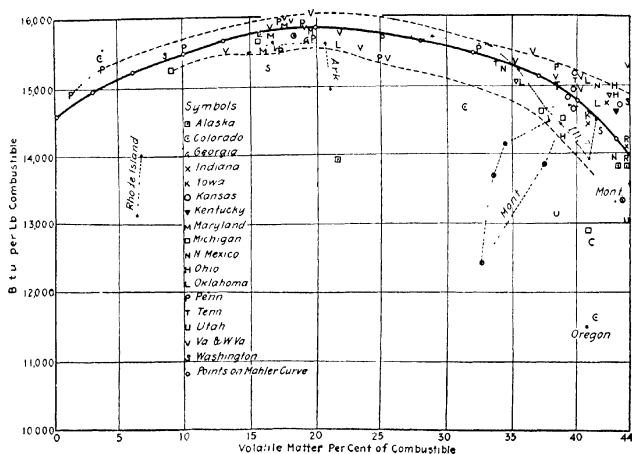
C. RELATION OF HEATING VALUE TO VOLATILE CONTENT

—A.S M.E.

constant. This method has the advantage of including the constant errors due to changes in specific heat of water, in cooling correction and in the thermometer, and to heat input from stirring. The value can, however, be determined absolutely by all-electrical methods.

Calculation of Heating Value from Analysis.—Figure C, by *Wm. Kent*, shows the relation between the heating value of coals and the % of *volatile matter* in the combustible, as given in the *proximate analysis*. It is based on 155 typical analyses chosen from 3000 collected by the *Bureau of Mines*, and shows that for Appalachian coals with less than 35% volatile in the combustible the actual heating value approximates the relation deduced by *Mahler* for European coals, and that the heating value for such coals can therefore be estimated from this chart, but that Western coals and high-volatile coals do not follow any law in this respect. It will be noted that most of the semi-bituminous coals have a heat value around 15,750 *BTU*.

F. C. Evans gives the following formula for the heating value of Ill. and Mich. coals:

$H.V. = 16062 — 3830V$

and for other states:

$H.V. = 14550 + 7810V$, for $V < 0.16$
$H.V. = 16160 — 2250V$, for $0.16 < V < 0.36$
$H.V. = 18750 — 9440V$, for $0 36 < V$

$H.V. =$ heating value of combustible, *BTU* per lb. (moisture-and-ash-free basis)

$V =$ fraction of volatile matter in combustible (*i.e.*, in coal free of ash and moisture)

Percentage of Fixed Carbon in Combustible

A. RELATION BETWEEN FIXED CARBON AND THERMAL VALUE

% Fixed Carbon in Combustible is Obtained From % Carbon in Fuel by Use of Upper Corner of the Diagram

Fig. A, by *W. C. Stripe*, shows the approximate relation of the heat value to the fixed carbon content by the *proximate analysis*.

The *ultimate analysis* can be used to compute the heating value of a coal by substitution in *DuLong's* formula, which is

BTU per lb. of coal $= 14,544C + 62028[H — (O/8)] + 4050S$

wherein C, H, O and S are the fractions of carbon, hydrogen, oxygen and sulphur, respectively.

There are several objections to this formula. The heating values of the elements have not been established with any great degree of accuracy. The heating values of elements in a free state and as component parts of a chemical compound are not necessarily the same. They usually vary, due to absorption or evolution of heat in the forming of a compound. The assumption that all of the oxygen is combined with the hydrogen is not true. In low-grade Western fuels, about two-thirds of the oxygen is in combination with carbon. For such coals, DuLong's formula would give heat values too low by assuming that all the oxygen is in combination with hydrogen. The relative accuracy is subject to the uncertainty of the oxygen determination, and the cost of making the ultimate analysis is high.

—Power.

DuLONG'S FORMULA FOR HEAT VALUE OF COAL

Assume a coal having the following ultimate analysis Carbon, 79 90%, hydrogen, 4.98%; oxygen, 4 31%, nitrogen, 1 85%, sulphur, 1 13%, ash, 1 83%; moisture, 2.91%. The upper heavy dotted line shows that the carbon represents approximately 11 660 *BTU.* The lower heavy dotted line shows that approximately 2,750 *BTU* must be added for the 4.98% hydrogen, when 4 31% oxygen is present The light dotted line shows that approximately 45 *BTU* will be obtained from the 1 13% sulphur The summation of these three values gives 14,455 *BTU* as the total approximate thermal value of this fuel. Calorimeter tests on coal of the foregoing analysis have shown a value of 14,380 *BTU,* hence the results obtained graphically are satisfactory.

The above chart, due to *W. C. Stripe,* is plotted from DuLong's formula. It gives results as accurate as those given by calculations.

The calorific value of coal, ash-free and moisture-free, is equal to the calorific value as determined in the calorimeter divided by one minus the sum of the moisture and ash. This is found to be fairly constant for the same coal bed in adjacent mines. The greatest deviation in any mine is less than 1%.

S. W. Parr states that the heating values of "unit coal," calculated by the method described on p. 60, are characteristic of the veins from which the fuels are taken, and are not affected by variations of ash and sulphur in different samples, or in a sample which is divided into two parts by the "sink and float" process, as shown by the following table:

A. RELATION BETWEEN FIXED CARBON AND THERMAL VALUE

% Fixed Carbon in Combustible is Obtained From % Carbon in Fuel by Use of Upper Corner of the Diagram

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small percentages of oxide of magnesium (MgO), oxide of sodium (Na_2O) and oxide of potassium (K_2O).

The table below gives an idea of the percentages of each of the constituents:

Coal	Total Ash, %	Constituents of Ash expressed as per cent of Total Ash							
		$Si O_2$	Al_2O_3	Fe_2O_3	CaO	SO_2	MgO	K_2O	Na_2O
Anthracite	7.26	25.66	27 03	42 83	1.56	17	11 83		
Semi-bit.	7 50	54 80	29 20	6 80	1.40	1.00	60	2.10	1.90
Bituminous	17.40	47.30	34.60	9.80	1 20	10	40	2.50	2.10
Bituminous	8.20	15 20	8 60	13 30	18.10	26 90	10 00	1 80	5 30
Bit. Slack	11.40	53 20	26 00	15 80	1 00	40	.70	1.60	.30
Lignite	16 60	39 30	24 08	3 80	14.90	12 50	1.70	.40	.10

Analysis of Refuse.—The proposed Test Code of the *American Society of Mechanical Engineers* provides that after removal of ash from the ashpit, it shall be quenched with water to stop the burning of any combustible carried over. If the total ash can be crushed down to maximum pieces not over $3/4$-in. diameter, the gross sample shall be collected according to the *standard method*, in increments having a proportion of about 50 lb. for each ton weighed out, unless the gross sample so collected would weigh less than 1000 lb., in which case the increments shall be large enough to result in a gross sample of 1000 lb., or if the total is less than 1000 lb., it shall be used as the gross sample. Increments shall be collected in galvanized-iron cans with tightly-fitting covers to prevent evaporation, removed only when adding increments. If it is not feasible to crush the fine refuse and clinker in one operation, the *alternate method* of sampling is used, in which the total is passed through a 2-in. mesh wire screen, and if any unburned combustible remains over the screen, it is separated by hand picking, crushed, and thrown in with the fine ash The "wet clinker" and "wet ash plus combustible" so separated shall be weighed, individually crushed and mixed, and recombined in proportion by weight, for the gross sample, taking increments of 50 lb. per ton of screened ash, unless the total sample so collected is less than 1000 lb. The gross sample collected in either way shall be systematically crushed, mixed and reduced in quantity according to Table 1 of *A.S.T M.* specification, page 27, for the *laboratory sample* for determination of combustible.

A grab *moisture sample* of 10 to 20 lb. shall be taken from the uncrushed gross sample, first turning it over several times with a shovel, as rapidly as possible to minimize moisture loss, and placed in a sealed container. This sample shall be quickly crushed down in a jaw crusher to pass through a 4-in. mesh sieve, reduced to approximately a 5-lb. sample, weighed quickly, spread over galvanized-iron pans (page 31), dried in air-drying oven with air at not over 200° F. until weight loss is not more than 0.1% per hr. Combustible in refuse shall be computed by means of difference in weight of total coal, computed weight of total dry ash from the ultimate analysis, and weight of boiler refuse, the heating value of the combustible to be taken as that of pure carbon. For determination of the combustible in fuel siftings through the grate, the sifting sample shall be treated according to the *A. S. T. M.* proximate-analysis method for ash in coal, and the heating value of the combustible in the siftings determined by the calorimetric method.

For powdered coal, the gross ash sample from the furnace shall be collected and weighed at convenient intervals, care being taken that none of the fine ash deposit is lost. If there are large slag formations, these

should be broken down and weighed separately. For the stack-ash sample, an efficient cinder catcher through which the total gases are passed will lead to more accurate results than any sampling device which takes only a small fraction of the total gases. Furthermore, due to the relatively slow movement of the gases, it is impossible to obtain a representative sample by simple means through a small sampling tube, as there is insufficient kinetic energy in the particles to carry them through such tubes.

Where it is impracticable to have the total gases passed through a cinder catcher, the method of the *Chicago Department of Smoke Inspection* and that of the *Bureau of Mines* at the Oneida Station have been used with success. In the Chicago device a tube was inserted in the stack at least 2½ diameters above the breeching or bend, and a gas sample was drawn out through a renewable cylindrical filter. The velocity of withdrawal was regulated to correspond with that of the stream, using a differential gage, and the volume withdrawn measured by a gas meter. The Oneida method gave an indication of the fine dust, as well as the cinder content, in the
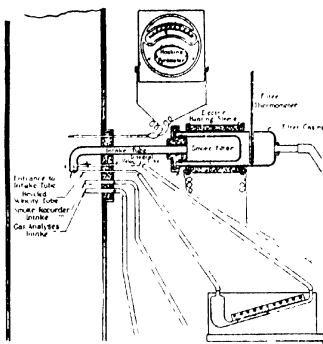
CHICAGO SOOT SAMPLER
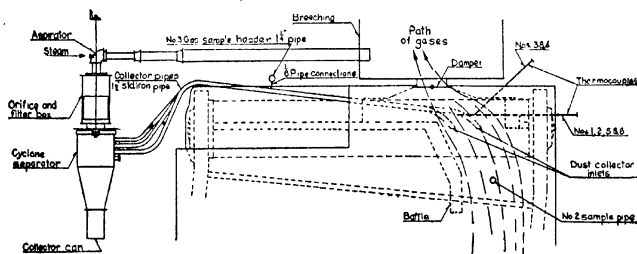
FLUE-DUST COLLECTOR, ONEIDA STATION

gases from the powdered-coal furnace. 1000 lb. of gas per hr. were drawn off, at a velocity greater than of the stream, through six 1½-in. pipes with intakes distributed equally over the area of the uptake and directed against the gas stream. The refuse was separated in a cyclone, 90% of the dust collecting in a detachable can at the bottom and 10% being removed in an excelsior filter, which was weighed from time to time, while the gas flow was calculated from the drop in pressure through a 4-in. escape orifice.

Separate laboratory samples weighing from 2 to 5 lb. shall be prepared

from both the gross furnace-ash and stack-ash samples by the standard process of reducing, accompanied by quartering and mixing, and analyzed for combustible according to the standard method. If the slag is to be analyzed the sample shall be prepared by crushing all of the slag so that it will pass through a 3/16-in. screen, and the laboratory sample prepared by the standard reducing process.

Determination of Phosphorus in Ash.—*Method No 1   To Cover All Cases.*—To the ash from 5 g. of coal in a platinum capsule is added 10 c.c. of HNO_3 and 3 to 5 c.c. of HF. The liquid is evaporated and the residue fused with 3 g. of Na_2CO_3 If unburned carbon is present, 0.2 g. of $NaNO_3$ is mixed with the carbonate. The melt is leached with water and the solution filtered. The residue is ignited, fused with Na_2CO_3 alone, the melt leached and the solution filtered. The combined filtrates, held in a flask, are just acidified by HNO_3 and concentrated to a volume of 100 c.c. To the solution, brought to a temperature of 85° C., is added 50 c.c. of molybdate solution and the flask is shaken for 10 minutes. If the precipitate does not form promptly and subside rapidly, add enough NH_4NO_3 to cause it to do so The precipitate is washed six times, or until free from acid, with a 2% solution of KNO_3, then returned to the flask and titrated with standard $NaOH$ solution. The alkali solution may well be made equal to 0 00025 g. phosphorus per c.c., or 0 005% for a 5-g. sample of coal, and is 0.995 of one-fifth normal Or the phosphorus in the precipitate is determined by reduction and titration of the molybdenum with permanganate.

The advantage of the use of *HF* in the initial attack of the ash lies in the result-ing removal of silica. Fusion with alkali carbonate is necessary for the elimination of titanium, which if present and not removed will contaminate the phospho molybdate and is said to sometimes retard its precipitation.

Method No 2.—When titanium is so low as to offer no objection, the ash is decomposed as under method No. 1, but evaporation is carried only to a volume of about 5 c.c The solution is diluted with water to 30 c.c., boiled and filtered. If the washings are turbid they are passed again through the filter The residue is ignited in a platinum crucible fused with a little Na_2CO_3, the melt dissolved in HNO_3 and its solution, if clear, added to the main one. If not clear it is filtered The subse-quent procedure is as under method 1 The fusion of the residue may be dispensed with in routine work on a given coal if it is certain that it is free from phosphorus.

Clinker is formed by the mechanical adhesion of the particles of ash, or by the fusing of the ash, thereby forming slag. An ash having a fusing temperature above 2700° F. will rarely give trouble if the coal is properly fired.

Clinker is of two types, hard clinker and soft clinker. Hard clinker is formed by the direct melting of the ash, or of some of its constituents. It hardens while in the ash on the grates. If formed by a portion of the ash melting, it will be in the form of a large hard cake at some point on the grate. If formed through certain constituents in the ash melting, it will be found as a number of small hard clinkers distributed throughout the ash. The caked hard clinker is usually the direct result of bad firing methods. The ash next to the grate is considerably cooler than the burn-ing coal in the fire bed, so that an ash that will not fuse when next to the grate will fuse when raised into the burning coal of the fire bed. Once melted, it runs down, is cooled and hardened, cementing pieces of coal and ash together. Small hard clinkers are formed by the fusing of certain in-gredients of the ash. Usually they do not cause serious trouble. Any working of the fuel bed tends to cause partially melted or softened par-ticles of ash to adhere to one another and thus to produce clinker.

Soft clinker remains molten while on the grates, but hardens when its temperature is sufficiently reduced. Once formed, the soft clinker continues to grow in size, until practically the entire grate is covered. It is formed by the slagging of the ash. It is not directly chargeable to bad methods of firing, although this may start the formation and hasten its spread. Soft clinker may have a consistency varying from that of a thick paste to that of a very heavy oil. The more fluid clinker is, the more troublesome, because it spreads faster. When first formed, a soft clinker is similar in appearance to a hard clinker. Inspection shows that it has a crust on the upper surface, underneath which it is fluid. Soft clinker is formed by the silica of ash combining with the base that has the lowest fusing temperature. Once formed, the silicate dissolves both the silica and the base, and in this way grows in extent. Silica is infusible at ordinary temperatures. The basic oxides of the ash are refractory materials, and are quite infusible at furnace temperatures. However, they act as fluxes for the silica, and promote the fusing. The silica acts as an acid flux, whereas the oxides act as a basic flux.

Before the subject of clinkering can be put upon a satisfactory basis, two kinds of measurement are necessary ·

(a) The determination of the extent to which the clinkering of a given coal is objectionable in actual use. The important factor is not so much the total volume or weight of clinker formed as the kind of clinker. Large amounts of non-adherent clinker are not particularly objectionable, while small amounts of clinker which form pasty masses give much trouble. Probably the only reliable basis at present for determining objectionableness is the judgment of the fire-room observer.

(b) The determination by laboratory test of some characteristics of the ash which indicates the probable degree and objectionableness of the clinkering.

There is no definitely-known, invariable relation between the chemical composition of ash and the fusing point. The only kind of a laboratory test of real value is one that will show the melting point of ash. The melting point cannot be judged from the chemical analysis. In most ash, SiO_2 predominates, and therefore the fusing temperature decreases as the percentage of lime and iron increases, but in view of the large number of factors affecting the chemical composition of coal ash, no close estimate of the fusing temperature can be made from the analysis.

FUSING TEMPERATURE OF ASH

The results of laboratory tests are not directly comparable to furnace conditions, as the laboratory sample is ground and intimately mixed, while in a furnace the intrinsic ash of the coal itself may fuse at a low temperature and bind together into large clinkers the infusible lumps of slate and bone mixed with the coal, in much the same manner as the rock aggregate in concrete is held together by the cement, and yet the laboratory test made on the finely-ground mixture may show a relatively high fusibility, due to the masking effect of the infusible slate and bone in the mixture. However, to place the determination of "softening" and "fusing" temperatures on a uniform basis, the *Bureau of Mines* and the *American Society for Testing Materials* have tentatively adopted the following method, D22-24, in which the ash is heated by burning in an excess of gas, keeping the air supply down and increasing it only as it becomes necessary to give the
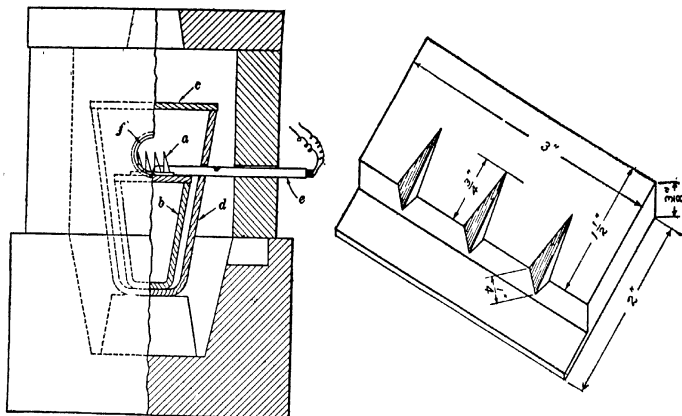
a, Ground ash cones; *b,* Supporting crucible; *c, d,* Clay muffle; *e,* Thermocouple tube, *f,* Observation tube.

GAS FURNACE FOR ASH FUSION TESTS, WITH MOULD FOR CONES

higher temperature. This gives a "reducing" atmosphere, by which the iron in the ash is reduced mainly to ferrous oxide, which forms compounds with silicates which fuse at low temperatures. If the iron were oxidized to ferric oxide, or if so strong a reducing atmosphere were used as to reduce the iron to a metallic state, the slag formed would indicate a deceptively high fusing temperature.

The No. 3 Melter's Furnace of the *American Gas Furnace Co.* is used, which is a pot furnace with three burners arranged on a tangent near the base, producing a rotary flame that completely surrounds the crucible in which the cones are placed. Natural or artificial gas is used, with compressed air at 3 lb. per sq. in. The stock design is modified by providing the upper cylinder with a 2-in. observation hole with its center 4 in. from the top of the cylinder, excluding the cover plate, and 1-in. thermocouple hole 90° to the right of it. The exterior of the furnace consists of three easily replaceable fireclay parts as shown, the internal diameter being 7 in. The joint between the upper and lower cylinders is made fairly gas-tight by a thick paste of alundum cement. The ash cones *a* are supported on a plate of alundum cement serving as a cover for crucible *b*, which is a Denver fireclay hard burned crucible, 3½ in. high. The outer crucible *d* with the cover *c* serves as a muffle and should be provided with observation and thermocouple holes. Fireclay crucibles will stand 1500° C. and last about six runs, while corundite crucibles and covers are good for fifty runs. A fused silica or refractory porcelain tube *e,* 1⅞ in. in external diameter and 6 in. long, is placed in the 2-in. observation hole of the furnace, the inner end being flush with the inside furnace wall and the other end projecting out of the furnace. A brass sleeve carrying a

thin glass window is slipped on the outer end of the observation tube to prevent the escape of burning gas, which would interfere with a convenient observation of the cones. At furnace temperatures above 1000° C., it is very difficult to observe the ash cones. A porcelain blowing tube ¼ in. in diameter is inserted through the same hole as the thermocouple tube. This tube has small perforations along one side by which air may be forced upon the cones at the time of making the observation, thus momentarily cooling the ash cones and rendering them visible, and is connected to the compressed air line by means of rubber tubing, the air being let into the tube at the time of observation by means of a pinchcock.

The test cone is made as follows: 50 to 100 grams of 60-mesh coal is spread out on a 6-in. fire-clay roasting dish, and completely converted to ash in a muffle furnace at 800° to 900° C. 5 to 10 grams of the ash are ground to 200-mesh in a hand or mechanical agate mortar, and then ignited for two hours in a current of oxygen, at 800° to 850° C, in a silica or porcelain capsule, ⅝ in. deep and 1¼ in. in diameter, to insure complete oxidation. The ignited ash is moistened with 10% dextrin solution, worked with a spatula and moulded into a small half-pyramid in a brass mould as shown, and mounted when dry in a refractory base made of equal parts of kaolin and alumina on a small sheet-iron plate. Usually five cones

are mounted on a base, and ignited at a dull red heat for 30 minutes in an open muffle to remove carbonaceous material. The test piece is placed in the muffle furnace in the position shown, the loosely fitting cover *c* is added, and the gas is burned about 10 minutes before the top cover plate is put on. The flow is then regulated to cause combustion to take place just above the tuyère and yet maintain a yellowish flame at least 6 in.

ASH-FUSION CONES AFTER SOFTENING IN FURNACE

above the opening in the furnace cover plate. After reaching 800° C., the temperature is increased at a rate of from 5 to 10° C per minute, maintaining the 6-in. reducing flame until at least 1450° C. is reached. The following temperatures are noted for each sample:

1. Initial deformation, when the first rounding or bending of the apex takes place, as distinguished from shrinking or warping. See Cone No. 1 in the photograph.

2. Softening temperature, when the cone fuses to a spherical lump, as in Cones 2 and 3. Cone 4 has almost reached the softening temperature.

3. Fluid temperature, when it spreads out in a thin layer, as Cone 5.

Crucibles which will stand 1500° C. (2732° F.) will do for most coals, any ash that remains solid above that temperature can be regarded as fusion-proof. A thermocouple may be used for measuring temperature within such range, made of platinum and platinum-rhodium, protected by a glazed porcelain tube with a high-resistance millivoltmeter, or an optical pyrometer can be used. At high temperatures the cones are rendered visible by blowing air onto them. For ordinary purposes the investigation can be stopped at 1500° C., the table on page 67, however, includes tests carried to higher temperatures in a molybdenum-wire resistance fur-

nace with an atmosphere of hydrogen gas. The equipment should be checked frequently by mounting small pieces of pure gold or nickel wire or foil in the same manner as the cones. With a strong reducing atmosphere, 1452° C should be obtained for the melting point of the nickel and 1063° C. for the gold. The pyrometer equipment should also from time to time be standardized by a standardizing laboratory through the temperature range for which it is used. The permissible difference of the softening temperature in duplicate determination is 30° C by the same analyst and 50° C. by different analysts.

Three main classes of ash can be made, according to the softening temperatures:

Class *A*, refractory ashes, softening above 2600° F, and giving no trouble from fusion, including anthracite coals and the lower and older bituminous beds.

Class *B*, ashes of medium fusibility, softening between 2200° and 2600° F, including the bulk of the Pennsylvania bituminous beds.

Class *C*, easily fusible ashes, softening below 2200° F, and subject to clinkering trouble.

The general characteristics of several hundred samples tested by the *Bureau of Mines* were as follows:

Ohio, *B*

Pennsylvania bituminous and semi-bituminous, mostly *B*, some *A*.

Pennsylvania anthracite, *A*

West Virginia semi-bituminous, principally *A* and *B*, Beckley bed, *A*.

Maryland, many *A* or upper part of *B*.

Eastern Kentucky and Virginia, all classes.

Tennessee and Alabama, mainly *B*

Illinois, Indiana, Western Kentucky, Kansas, Missouri, Oklahoma, Arkansas, principally in Class *C*, due to pyrite, calcite and gypsum in beds

Alaska, *A* and *B*

Washington, mainly *A* and *B*, high ash, largely refractory.

Colorado and New Mexico, mainly *A* and *B*

North Dakota, South Dakota, Montana lignites, Montana and Wyoming sub-bituminous, Class *C* or lower part of Class *B*.

AVERAGE FUSIBILITY OF ASH

Series, Bed	Number of Mines Sampled	Total Number of Samples	Average Softening Temperature, Deg. F	Ash in Dry Coal Average Per Cent	Sulphur in Dry Coal Average Per Cent
Pennsylvania Bituminous Region—					
Monongahela Series					
Pittsburgh Bed 10	10	34	2360	7 17	1 43
Conemaugh Series.					
Little Pittsburgh Bed ...	1	2	2390	8 13	1 70
Allegheny Series					
Upper Freeport (E or Lemon) Bed . . .	33	85	2350	9 35	2 13
Lower Freeport (D or Moshannon) Bed	21	70	2390+	8 52	2 06
Upper Kittanning (C Prime) Bed	7	18	2350+	8 67	2 16
Middle Kittanning (C) Bed	5	7	2380+	. 11.06	2 98
Lower Kittanning (Miller or B) Bed.	39	162	2550+	7.86	2.03
Fulton Bed	4	12	2940+	7 36	1 18
Brookville (A) Bed.......	3	3	2800+	12.98	1 86
Pottsville Series:					
Bloss Bed	3	. 3	2630	11.96	2.25

	Number of Mines Sampled	Total Number of Samples	Average Softening Temperature, Deg. F.	Ash in Dry Coal, Average Per Cent.	Sulphur in Dry Coal Average Per Cent.
Pennsylvania Anthracite Region—					
Northern Field:					
Pittston District	1	1	3010+	6.03	0 58
Plymouth District	2	7	3010+	12.52	0.84
Scranton District	6	7	3010+	12.39	0.79
Wilkes-Barre District	3	4	3010+	13.17	0.78
Eastern-Middle Field:					
Hazleton District	1	1	2960	14.50	0.61
Western-Middle Field:					
Shamokin District	2	2	2960+	16.59	0.90
West Mahanoy District.....	3	3	3010+	....	...
Southern Field:					
East Schuylkill District....	2	2	2990	11.19	0 78
West Schuylkill District..	1	1	2730	18 07	0.82
Central Region—					
Illinois:					
No. 1 Bed...............	1	6	2110	11.74	4.86
No. 2 Bed...............	6	15	2010	9 97	3 58
No. 5 Bed...............	9	27	1990	10.84	3 28
No. 6 Bed...............	36	160	2160	10.27	2.30
Indiana:					
No. 3 Bed...............	3	11	2090	10 61	4.34
No. 4 Bed...............	7	30	2390	8.17	1.62
No. 5 Bed...............	9	29	2130	10.23	3.54
No. 6 Bed...............	1	5	2040	9 91	2.65
Minshall Bed	1	1	2120	9.60	2.99
Western Kentucky:					
No. 6 Bed...............	1	..	2130	8.81	2.97
No. 9 Bed...............	20	78	2030	10.53	3.67
No. 10 Bed...............	2	2	1990	11.99	4.18
No. 11 Bed...............	7	39	2030	9.57	4.08
No. 12 Bed	3	17	2150	10 20	2.30
Western Region—					
Kansas:					
Bevier Bed	2	6	1980	14.83	4.71
Cherokee Bed	3	8	2110	9.42	3.18
Leavenworth Bed	1	3	2020	18.26	5 46
Weir-Pittsburgh Bed	3	7	2010	11.68	5.31
Missouri:					
Bevier Bed	16	42	1960	13.47	4.90
Vainsville Bed	1	3	1980	12.71	5.78
Cherokee Bed	1	3	2150	7.51	1 97
Jordan Bed	4	12	2010	12.74	4.42
Lexington Bed	14	39	2000	13.48	4.04
Lower Rich Hill Bed.....	3	8	1940	15.39	5.43
Lower Weir Pgh. Bed.....	2	6	1940	10.78	4.45
Mulberry Bed	2	5	1990	14.58	3.18
Mulky Bed	4	9	1940	11.28	5.25
Rich Hill Bed............	1	3	1970	15.47	6.12
Tebo Bed	8	23	2040	11.64	4.66
Waverly Bed	1	2	2020	17.43	8.29
Oklahoma:					
Dawson Bed	3	3	1920	8.95	3.91
Henryetta Bed	2	2	1980	8.03	1.59
Lehigh Coal Bed..........	3	15	2150	11.46	4.17
Lower Hartshorne Bed....	9	27	2020	6.03	1.43
McAlester Bed	6	28	2180	6.94	1.67
McCurtain Bed	1	6	2110	6.92	0.84
Panama Bed	2	4	2160	6.81	1.46
Stigler Bed	5	5	2050	5.13	1.91
Upper Hartshorne Bed....	3	7	2170	6.15	1.51
Arkansas:					
Denning Bed	1	3	2200	7.38	2.45
Hartshorne Bed	5	9	2120	11.59	1.40
Paris Bed	1	3	2140	10.12	3.28
Shinn Basin Bed..........	1	1	2180	10.36	2.23
Southwestern Region—					
Texas:					
Santo Thomas	2	2	2580	19.21	1.98

J. A. Murray gives the following table, showing that the chance of getting a coal with a fusion point over 2500° F. decreases as the percentage of sulphur increases.

RELATION OF SULPHUR TO FUSION POINT

	──% Sulphur in Dry Coal──				
	Under 1	1 to 2	2 to 3	3 to 4	Over 4
Number of samples with a fusion point above 2500°	210	373	57	5	0
Number of samples with a fusion point below 2500°	51	268	86	56	57

This is not due to the effect of the sulphur itself, but to the iron which usually accompanies it. The tabulation is based on 1163 weekly samples taken at the *Detroit Edison Co.*, from mines in the Cambridge district in Ohio, the Kanawha, Logan and Thacker districts in West Virginia, and the Eastern Kentucky district.

The *Bureau of Mines* states that coal ash which is extremely high in silica or in bases is not readily fusible, and that ash which is low in iron is usually not readily fusible. In coals containing considerable pyrite, the iron is apt to be converted to ferrous oxide in the fuel bed, which with the silica present forms ferrous silicates that fuse at comparatively low temperatures. The chemical analysis of a series of five coal ashes ranging from very fusible (softening at 2060° F.) to highly refractory (softening above 2900° F.) is as follows:

CHEMICAL ANALYSIS OF FIVE COAL ASHES COVERING A WIDE RANGE
OF FUSIBILITY

Sample No.	Softening temperature, ° F.	Analyses of ash, percentage of—								
		SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	SO_3
1	2,060	30.7	19.6	18 9	1 1	11.3	3.7	1.9	0.5	12.2
2	2,320	46.2	22.9	7.7	1 0	10.1	1.6	.7	.8	8.9
3	2,500	49.7	26.8	11.4	1.2	4.2	.8	1.6	1.3	2.5
4	2,730	51.0	30 9	10.7	1.9	2.1	.9	1.0	.4	.6
5	+2,900	58.5	30.6	4 2	1.8	2 0	.4	.7	.9	.9

Sample No. 1, sub-bituminous coal, No. 3 bed, Montana; No. 2, bituminous coal, No. 6 bed, Illinois; No. 3, bituminous coal Pittsburgh bed, Pennsylvania; No. 4, semi-bituminous coal, Pocahontas No. 3 bed, West Virginia; No. 5, bituminous coal, Dean bed, Kentucky.

THE VALUE OF COAL FOR STEAM PURPOSES

In discussing the value of a coal, the terms efficiency, economy and capacity may become confused. A study of the coals available may show the advantage of using a low-priced coal that gives 65% furnace and boiler efficiency, as against a higher-priced coal that gives 75% efficiency. The efficiency of the dollar is the final criterion. An increase in capacity at a sacrifice of efficiency may make for economy, by saving fixed charges on additional boilers and equipment.

In determining the actual cost of coal, include the price delivered at the generating station, the cost of unloading into the bunker, the cost of moving from the bunker to the fire, the cost of removing and disposing of the ash, and the interest on the capital tied up in the reserve fuel supply.

Gould says that variations in quality equal to 10 or 15 cents per ton can occur without being noticed and reported by the fireman, and that figures prove that big variations in value are occurring every day in the coal delivered. It is human nature for a dealer to see that his better coal goes to the buyer who has the facts.

Since the smaller sizes of steam anthracite sell at lower prices, it is important to use the smallest size of anthracite possible. The equipment of a plant determines the size to use, but it is important to see that the size ordered is received. If 50% of the coal is undersized, you are losing not only the difference in the market price, but are losing too much through the grates. Bituminous and semi-bituminous coals vary in value even more than anthracite.

It is possible for several coals to show the same calorific value in the calorimeter and yet differ as much as 3 or 4% in actual commercial value as steam producers. It is advisable to have the laboratory fuel test supplemented by data obtained by measurements of fuel consumed and water evaporated.

G. C. Cook suggests as the factors to be considered in selecting a coal: the market conditions, the character and type of boiler-room equipment, the load and service requirements, the boiler-room personnel and the requirements as to smoke. Careful investigation should be made to ascertain the ability of the dealer to furnish a supply uniform in quality and in quantity, also the ability of the fuel to stand shipment. Sub-bituminous coals and lignite suffer much deterioration in handling. If a large supply must be kept on hand, the tendency to spontaneous combustion must be ascertained. Sub-bituminous coals and lignite, and bituminous coals in a finely divided state, are subject to such spontaneous combustion.

The following characteristics of the equipment should be considered:

A furnace with a small volume of combustion space or short flame travel is not adapted to burning high volatile coals at high rates of combustion.

Furnaces having a tile roof or Dutch oven are usually well adapted to burning high volatile coals, because of the larger combustion space and the maintenance of the heated brick work at the high temperature required for ignition. Arches, brick piers and wing-walls, which effect a more thorough mixture of air and combustible gases, will permit the use of higher volatile coals. In hand-fired furnaces the arch or tile roof should not be over the grate but above or beyond the bridge-wall. This position of the arch reduces the rate of heating of the freshly-fired coal and spreads the distillation over a longer period.

Plain grate bars are used with larger sizes of coal and with coals that produce considerable clinker, while herringbone or pin-hole grates are used with finer sizes. Shaking and dumping grates require less labor, and can therefore be used with high ash coals.

In stoker installations, it must be borne in mind that no type of stoker burns all sizes of coal with equal facility. For instance, highly caking, low ash coals are not suited to the chain grate. This is best adapted to the free-burning, high-ash coals of the Middle West.

Where the draft is low, the larger sizes of coal of the free-burning type should be used. Coals that require a high draft are lignite, sub-bituminous and fine sizes of anthracite.

Draft requirements are affected by size, caking quality, ash content and clinkering qualities of coal.

Where manual labor is used, the handling of the coal and refuse is an item to be considered.

If the plant has a steady load and a high rate of combustion or a fluctuating load with heavy peaks, there will be difficulty in burning coals whose ash fusing temperatures are low. With a high rate of combustion the furnace temperature is usually high.

Much of the credit for success or failure of a coal is dependent upon the skill of the operating force.

Where the plant is located in a city having a smoke ordinance, the fuel must be so selected that the ordinance will not be violated. Cinder production may also be a detriment. One of the greatest aids in comparing fuels is a service test.

Effect of Ash on Coal Value.—Next to calorific value ash content is the most important factor in the commercial valuation of coal. The efficiency of combustion ordinarily decreases with increase of ash. There is also the additional expense for ash disposal.

Commercial coals contain 3% to 25% of ash. Coals with the smallest ash percentages have the greatest value, not only because of their higher heating values, but because they offer less resistance to the passage of air and to its distribution through the fuel bed. The labor and cost of managing the fire and the handling of the ashes must be considered. The greater the ash content the lower the efficiency and the capacity.

High ash coals require higher draft, which results in more leakage of air through the furnace walls. The greater draft is required because the ash may form an insulating layer around the coal, so that the oxygen cannot come in contact with it. The ash may also clinker and clog the fuel bed. The following are the maximum limits of ash usually permitted in anthracite·

Furnace	10% of "dry coal"
Egg	11 " " "
Stove	12 " " "
Chestnut	14 " " "
Pea	16 " " "
Buckwheat No. 1.....	18 " " "

Walter N. Polakov states that the steaming capacity of coal decreases parabolically with increase in the ash, but at a slower rate as the ash increases. Figure A on page 72 is based on accurate data from a number of hand-fired plants using mixtures of hard and soft coal for a period of over 18 months. 14% ash coal averaged 9 pounds of steam per lb. of coal; with the increase to 18% it dropped to 8 pounds, and at 28% it was 7 pounds. High ash results in increased haulage, frequent need for cleaning fires, difficulty in judging proper air supply, and increased labor for handling coal and ashes, and in aggravating the car shortage by hauling unnecessary dead weight. A minimum of 60% efficiency was secured with a mixture of 1 part run-of-mine and 5 parts of anthracite screenings containing 45% non-combustible.
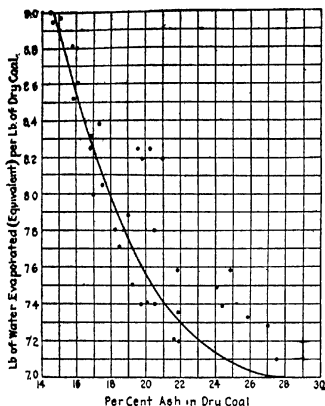
A. RELATION BETWEEN ASH
CONTENT AND EVAPORATION
—A S.M.E.
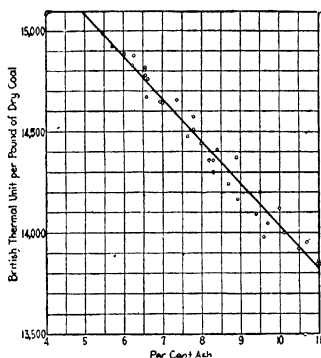
B. RELATION BETWEEN HEAT
VALUE AND ASH, W. VA. COALS
—Power.

Fig. B is by *Haylett O'Neill,* and shows the relation between ash content and heat value for West Virginia coals.

Fig. C, adjoining, by *Frank G. Philo,* indicates the relation between ash and heating value of No. 3 Buckwheat and anthracite, based on analyses and firing tests on a "sawdust" grate. The straight line indicates the heat content by the calorimeter, which decreases uniformly with rising ash content, in the case of anthracite, while the curve shows the *BTU* available for steam production, the dip being due to the fact that with the higher-ash coals a larger percentage of "combustible" escapes unburned with the ash.
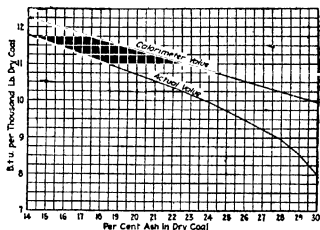
C. RELATION OF HEAT VALUE TO
ASH IN ANTHRACITE
—Coal Age.

W. L. Abbott states that tests were made, on a chain grate stoker, with increasing percentages of ash artificially mixed with the coal. Up to 35% ash the efficiency dropped gradually, and above 40% it was impossible to generate steam. 20% seems to be the upper economical limit for ash in steam-producing coal.

Henry Kreisinger says that while it is generally true that fuel with over 40% refuse is valueless, it can be burned under proper conditions, at the source of supply. The *Bureau of Mines* made tests with washery refuse containing 42% ash, burned under a 200 H.P. boiler, with hand-fired furnace and plain grate, the fire being cleaned every hour. While the frequent cleaning kept the average capacity down to 75%, an overall efficiency
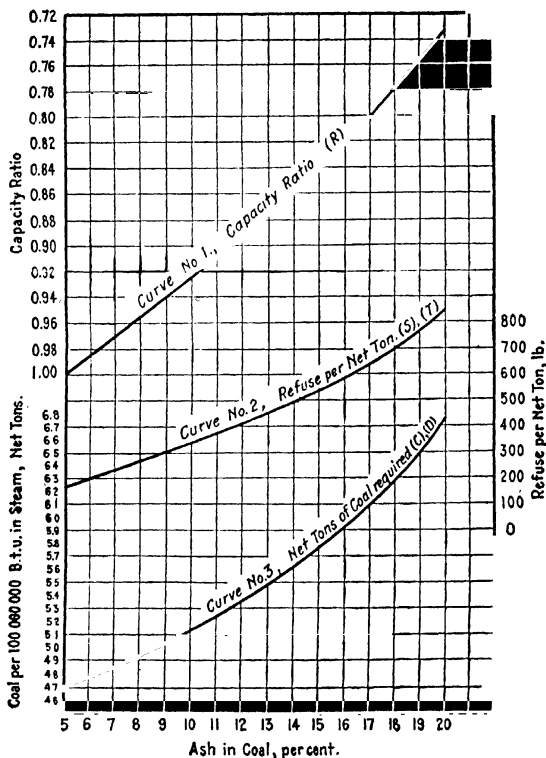
D. EFFECT OF ASH ON COST FACTORS

of 47% was secured, showing that it would pay to burn such fuel if provision were made for automatic removal of the ash.

E. B. *Ricketts* stated before the *American Society for Testing Materials* that having once determined the general type of coal suitable for a given plant, the cost of steam production is a function of the ash content. Complete boiler tests should then be made to determine, (1) the ratio of the maximum plant capacity with coal containing various amounts of ash from 5% up to 20% to the maximum capacity when using coal containing 5% ash, (2) the actual number of lb. of refuse to be handled per ton of

coal, for the various percentages of ash, (3) the number of tons required to generate 100,000,000 BTU, for the various percentages of ash. The results can be plotted, as in Figure D, which represents the average of observations at the *New York Edison Co.* (underfeed stokers, low-set boilers) and the *Cincinnati Union Electric Light & Power Co.* (underfeed stokers, modern settings) using coals with less than 20% volatile and ash-fusion temperatures not less than 2450° F

From these data and from the cost of handling and removing ashes and the prices quoted for the coals offered, the value of the various coals is figured, either considering or not considering investment cost:

$$Z = Y - (S - T)U \text{ or } Y^1 - (S - T)U$$
$$Y = CX/D$$
$$Y^1 = \frac{CX + 5.13B/A - 5.13B/AR}{D}$$

where Z = value in dollars per ton of $x\%$ ash coal in bunkers
  Y = value, not considering ash handling or investment
  Y^1 = value, not considering ash handling, but considering investment
  S = lb. of refuse per ton from $x\%$ ash coal (Curve No. 2)
  T = lb. from 5% ash coal
  U = cost of ash handling and removal in dollars per lb.
  C = tons of 5% ash coal to produce 100,000,000 BTU (Curve No. 3)
  D = same for $x\%$ ash coal
  X = cost in dollars per ton of 5% ash coal delivered in bunkers
  B = cost of boiler plant per maximum $HP.$, divided by 100
  A = load factor = total lb. steam generated per year divided by lb.
      generated in maximum hours multiplied by 8760
  R = capacity ratio (Curve No. 1)

Effect of Size of Coal.—The size of the coal influences the capacity of the boiler, owing to its effect on draft. With poor draft, fine coal cannot be burned in sufficient quantities to maintain the rated capacity. If thin fires are resorted to, the efficiency is usually lowered by holes in the fire. Dust and very fine coal check the air flow or pass up the stack unburned. Coal of uniform size is most satisfactory, as it does not pack so badly as other coal.

Effect of Moisture on Steam Value of Coal.—Moisture in coal reduces the efficiency of steam generating apparatus by

(*a*) Increasing the heat carried away by water vapor. 1% moisture means a loss of 13 BTU per lb. of coal, in superheated vapor in the stack gases when they have a temperature of 600° F.

(*b*) The escape of a larger quantity of free hydrogen.

Moisture also decreases the capacity, due to a lower rate of combustion, caused probably by dilution of the oxygen by a large quantity of water vapor.

Moisture reduces efficiency more than the same percentage of ash.

The "dry coal" analyses are convenient for comparing different coals. The chart opposite, adapted from *M. Gensch*, shows the effect of moisture on the value of a coal. It has been figured for average Illinois coal, and is fairly representative of the usual coals which contain moisture in sufficient amounts to have appreciable effects on economy. Since the price is at the mine or on delivery, excess above the minimum moisture at
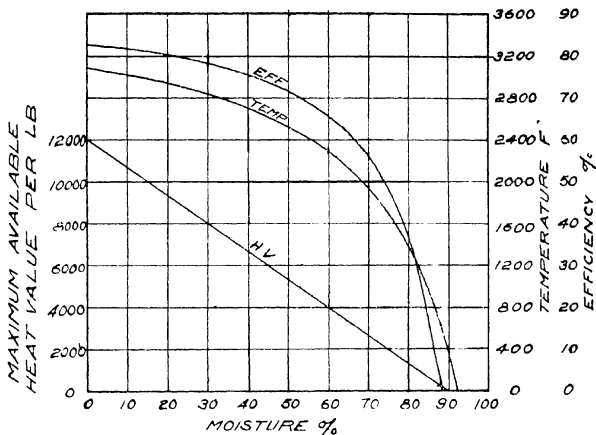
THE EFFECT OF MOISTURE ON THE VALUE OF COAL

Based on 12,000 *BTU* coal containing no moisture The maximum possible available heat is that obtainable above 600° F. flue gas temperature The temperature of combustion and the maximum possible efficiency are based on 50% excess air (16.5 lb. per lb of dry coal) and a flue gas temperature of 600° F

the mine is a pure loss to the purchaser. While moisture in coal is in general detrimental, due to the heat absorbed in evaporating and superheating it to the temperature of the flue gases, with some bituminous coals the moisture content produces a mechanical action that assists in combustion.

Kenneth M. Holaday suggests three arbitrary grades for coal, indicative of its desirability from the standpoint of moisture, ash and heating value, and that the average of these three grades be used as a basis for decision. The grading table below is typical, although the limits can be changed to suit local conditions, while the second table gives an example of a coal which graded 2.33, between poor and fair. A coal receiving a zero grade on any count should be rejected outright. A fourth grade can be introduced to cover ash-fusion temperature.

METHOD OF GRADING COAL

Grade		Moisture	Ash	Heating Value
5	Excellent	Below 5.0	Below 5 0	Above 11 500
4	Good	5 0—10 0	5 0—12 5	10.500—11 500
3	Fair	10 0—15.0	12.5—17.5	9.500—10,500
2	Poor	15.0—20 0	17 5—25.0	9,000— 9.500
1	Very poor	20.0—25.0	25.0—30.0	8,500— 9,000
0	Worthless	Above 25.0	Above 30.0	Below 8 500

EXAMPLE OF COAL GRADED BY THIS METHOD

	Analysis	Grading
Moisture	7.50%	4
Ash	27.50%	1
Heating value	9,250 *BTU*	2
Average (=poor to fair)....................................		2.33

Steaming values can be compared numerically by the following formula, which embodies a penalty of 50 cts. per ton of ash:

$M = (H \times 2,000) \div (P + \frac{1}{2} A)$.

$M = BTU$ modulus (net BTU purchased for a cent).
$H =$ heating value (BTU per pound), "as received" basis.
$P =$ delivered price, cents per ton.
$A =$ ash content, %.

If the heating value is reported on a dry-coal basis, it should be corrected to correspond to the moisture condition of the coal "as received."

On this basis, Coal B in the table below is seen to offer more heat units per unit of cost, although the cost per ton is higher:

COAL A

9,400 BTU per lb.
20% ash
$3.45 per ton

$$M = \frac{9,400 \times 2,000}{345 + 10} = 52,958.$$

COAL B

10,800 BTU per lb.
18% ash
$3.70 per ton

$$M = \frac{10,800 \times 2,000}{370 + 9} = 56,992.$$

Effect of Oxygen on the Value of Coal.—Oxygen in coal is a diluent or "dead weight." It renders ineffective an equal combining weight of carbon, hydrogen or sulphur. Whereas DuLong's formula combines the oxygen only with hydrogen, in highly oxygenated coals nearly two-thirds of the oxygen appears in the volatile in union with carbon.

A comparison of numerous boiler tests by the *Bureau of Mines* shows that the boiler efficiency drops as the oxygen content increases. There is no logical course of reasoning to demonstrate that the oxygen should in any way cause a large increase of air or incomplete combustion. The decrease in efficiency is probably due to other causes, as high oxygen content is associated with moisture or ash or both.

The Effect of Sulphur on the Value of Coal.—The sulphur in a coal and the heating value are largely affected by the ash. If unnecessary ash is kept out at the mine, sulphur will be low, and the BTU value high. *Marks* states that while the sulphur content of coal is generally considered to produce clinkering, spontaneous combustion and corrosion, its connection with the first two is not definitely substantiated by experience. It is also certain that sulphur fumes do not attack metals under conditions of boiler operation, although they probably do attack economizer tubes filled with cold water. (See page 69.)

Effect of Volatile on Coal Value.—The volatile content of coal is of indirect interest in indicating its general nature, but does not give any definite information about the burning qualities. The volatile in most coals includes some inert matter. The proportion varies in different coals, and therefore the heating value cannot be determined from the proximate analysis alone. Different coals with the same amount of volatile behave differently.

· The steaming value of coals is very nearly proportional to the BTU content. In a large number of tests by the *Bureau of Mines* on coals ranging in heat content from 14,600 to 10,200 BTU, the corresponding average efficiencies varied from 66 to about 62%.

THE PURCHASE OF COAL UNDER SPECIFICATIONS

Power plant economy can often be improved by the use of better methods in the purchase of fuel.

J. A. Moyer points out that specifications secure a more uniform grade of coal, which permits a more careful study of the operation of a boiler plant Operating conditions can be arranged to secure the best possible efficiency with the grade of coal supplied. Many operators believe this advantage is in itself worth the expense, which is considerable, of sampling and analyzing.

There are disadvantages in purchasing coal under specifications. most of which will eventually be overcome. The cost of the analyzing apparatus is considerable, and the services of a somewhat skilled man are required. Mine operators object to unreasonable specifications, and it is claimed that 90% of specifications offered are impossible in practical operation. The mine operator frequently adds 10% to his price for unexpected contingencies.

The *Bureau of Mines* mentions the following advantages:

1. The bidders are put on a strictly competitive basis.

2. The field is broadened for both bidder and purchaser.

3. The contract specifies an established standard of quality as a basis for adjusting the price.

4. If other coal must be substituted, there is a standard for settlement.

5. If coal is uniformly poorer than the standard set, there is a basis for cancellation.

6. When there is need of preparation at the mine (picking, washing, etc.,) the operator, who is largely responsible for variations in the grade of such coal, is stimulated to prepare it better.

The useful items in a modern specification for coal purchase are the heat value and the water and ash contents.

In plants where boiler capacity and grate area are small, and the draft is weak, only the best grades of coal can be burned. It is therefore desirable to take bids on such plants on a general specification, so that bids can be received on coals of different quality. With the information obtained, the probable saving which would result from making radical changes in the plant, in order to take advantage of coals offered at lower costs per million *BTU*, can be determined.

Specifying the district from which the coal is to come is no guarantee. Every district can supply coal varying easily 10% in heating value.

The Government accepts as anthracite coals those mined in Susquehanna, Lackawanna, Luzerne, Carbon, Schuylkill, Columbia, Sullivan, Northumberland and Dauphin Counties, Pa. It accepts as bituminous all those usually classed as bituminous, together with sub-bituminous and semi-bituminous. Specification limits are wide enough to permit the use of the output from a group of mines.

Government specifications describe clearly the quality of coal desired, with the intention of enabling the bidder to furnish a definite statement of the quality of coal offered, this statement to be used as a standard or as a basis of payment in connection with the price stated. The bidder is not required to submit a sample, but must state the percentage of ash and the *BTU* in the coal as delivered.

The bidder is required to furnish the commercial name of the coal he proposes to deliver, and the name or local designation of the coal bed or beds.

It is not expected that all deliveries will be absolutely uniform or agree exactly with the standard, but it is necessary that all deliveries shall come within the limits set.

It is important not to neglect the matter of the allowed percentage of fine coal or slack. Nut and slack contracts generally read that the coal that can be sifted or screened through a screen having ¼-in. perforations shall not exceed 30%.

Moisture.—Prior to 1912 and 1913, Government specifications were written on a *BTU*-as-received basis. Payment was directly affected by the moisture content of the sample received by the laboratory. The moisture reported by the laboratory may be 5% to 10% lower than that actually contained at the time of weighing. This means that payment on this basis would be higher than warranted. The *Bureau of Mines* recommends that specifications be on a "dry coal" basis.

In preparing specifications the fact is recognized that the moisture in a coal produced from day to day in the same mine will vary considerably, and is a matter over which either the buyer or the seller can exercise but little control. To place a negative value on high moisture coal and to protect the Government against coals of excessive moisture requires a statement of the maximum moisture content in the coal offered. This value becomes a standard for the contract.

If coal of uniform *BTU* on a dry coal basis is delivered, the contractor receives an advantage on a delivery on which the moisture content approaches the maximum specified, whereas if the coal is very dry the purchaser receives the advantage. It is equitable that the seller and the purchaser shall share the uncertainty.

The determination of moisture in coal delivered from a stock pile is of great importance, as it may be 10% to 15% higher than when stocked.

Neither the "as received" nor the "dry" basis has proved altogether satisfactory. A satisfactory way of handling the moisture question has yet to be evolved.

Ash.—A great deal of anthracite has been purchased by the Government on an ash standard basis only. The comparison of tests shows that the per cent. ash in "dry coal" is a good index of the heating value.

Few specifications in use make any mention of the clinkering qualities of coal, although they are of great importance, and should be covered in all specifications. The fusing temperature is a measure of the clinkering, but the method of determination should be further investigated.

Anthracite for all purposes may, according to standard specifications, carry a certain percentage of rock, slate, or bone, according to the size of coal. A piece of coal containing hardly any carbon is classed as rock. A piece containing less than 40% carbon is classed as slate. A piece containing from 40% to 65% carbon is classed as bone. A piece containing over 65% of carbon is classed as coal. Egg coal may contain 2% of slate or rock, and 2% of bone. It must be free from mud or discoloration. Stove coal may contain 4% of slate or rock, and 3% of bone It must be free from mud and discoloration. Chestnut or nut coal may contain 5% of slate or rock, and 5% of bone. It must be free from mud or discoloration. Pea coal may contain 10% of slate or rock, and not much more bone than slate. Its color must be fairly bright. No. 1 buckwheat may contain 15% of slate or rock, and not so much bone as to make the mass look dull in color. Rice coal may contain up to 20% of slate. Barley coal must retain a fairly bright appearance.

Sulphur.—The *Bureau of Mines,* in its recommendations for specifications, does not exact a penalty for sulphur content, but does require that the contractor specify the sulphur content so that standards for coals to be delivered may be established. Many commercial and municipal specifications exact penalties for a slight increase. One deducts 5% in price for each 1% of sulphur in excess above the standard.

Volatile.—Both sulphur and volatile contents should be used to classify coals and to identify the coal guaranteed Variations indicating substitutions of unsatisfactory coal should be considered a cause for rejection of the coal, or for cancellation.

In the *Bureau of Mines* specifications, the contractor is required to give the volatile content and the complete proximate analysis. This becomes a standard for the contract, and delivery of coal with different percentages of volatile, indicating substitution, may result in the coal being rejected and the Government purchasing coal in the open market, the contractor being charged with the difference in price, or in cancellation of the contract.

The Government does not consider a penalty for volatile variations equitable, because the per cent. of volatile does not indicate the character of the coal nor the heating value. Some commercial and municipal specifications apparently disregard this fact, and state penalties for volatile variations. This offers ground for opposition from coal companies.

Where smoke laws are to be observed it may be necessary to specify also a maximum volatile content for the coal. However, it would generally be advisable and economical to alter the furnace and boiler conditions to burn a cheaper high-volatile fuel.

Method of Sampling.—The method of sampling should be included in the specifications. Probably more difficulties arise on account of improper sampling than for any other reason. Mechanical means of sampling are considered the best. Alternate methods of analysis are not desirable, and standard specifications should always specify one standard practice.

Service Tests.—Specifications recommended by the *Bureau of Mines* provide that before a final award of contract practical service tests may be made to determine the relative suitability of the coals offered.

Bonuses and Penalties.—The *Bureau of Mines* suggests the following:

For adjusting the price on the *BTU* variation use the following:

$$\frac{BTU \text{ delivered}}{BTU \text{ standard}} \times \text{contract price} = \text{price to be paid.}$$

The price should be further corrected for variations in ash in the dry coal; for all coal which by analysis contains less ash than that established in the contract a premium of 1 cent per ton for each whole per cent. less ash would be paid, and an increase in the ash content of 2% over the standard established by the contractor would be tolerated without exacting a penalty for excess ash, but when such excess exceeded 2% above the standard established, deductions would be made from the price paid per ton in accordance with sample Government specifications, page 87.

Comparison of Bids.—After all bids have been received, they should be reduced to a common basis for comparison. The preferable method is to adjust them to the same ash percentage by selecting as a standard that proposal which offers the coal containing the lowest percentage of ash. Each one per cent of ash content above that of this standard is assumed to have a negative value of two cents per ton, the amount of the penalty which is exacted under the contract requirements for 1% excess of ash. The proposal prices are adjusted in this manner, and so tabulated. On the basis of this adjusted price, allowance is made for the varying heat values by computing the cost of 1,000,000 *BTU* for each coal offered. Thus the three variables are all merged in a single figure for comparison, including heat value, percentage of ash, and price per ton.

Bidder	Heat Value "as Received"	Ash in 'Dry Coal"	Price per Ton Bid	Plus Ash Dif.	Cost per 1,000,000 *BTU*, in cents
A	13400	10	$2 35	$2.43	8 096
B	14000	8	3.15	3.19	10.172
C	14600	6	3.25	3 25	9.938
D	13000	10	3.10	3.18	10.920
E	13000	8	2 35	2.39	8.207
F	13000	10.5	2 35	2 44	8.379
G	11500	13.5	2.25	2.40	9.317

Typical Specifications.—The outline opposite indicates the points to be considered in drawing up specifications. The sample specifications quoted in the following pages were prepared by the *Bureau of Mines* for the use of Government Departments.

U. S. GOVERNMENT SPECIFICATIONS AND PROPOSALS FOR BITUMINOUS AND ANTHRACITE COAL

I. Proposals

1. **Date to be Del . . ed.**—Sealed proposals, in duplicate, on blank forms supplied by the . . . . .to furnish such quantities of coal as specified here n as may be required for use of the. . . . . for the fiscal year ending June 30, 192.., will be received until 2 o'clock p. m., ..., at the office of the. . . . ., and then opened.

OUTLINE SPECIFICATION OF COAL

By *Morgan B. Smith*

Coal to be furnished
- Producer's or seller's bond—Surety Co.
- Trade name
- Region mined—state mines, seams
- Size limits, if any
- Quantity (Max.)
  - % allowed for varying requirements—pro rata tonnage in case of strikes
  - Reserve for test purposes—right to buy on open market—% of max. quantity

Purchaser's Option
- Rights in case of seller's failure to fulfill contract—annulment of contract clause

Shipments
- Notice to seller as to requirements
- Delivery
  - When—period
  - Where—tracks at yards
  - How—types of cars desired
  - Routing
  - Weights
    - Railway bills expense to purchaser
    - Purchaser's weights

Payments
- Price
  - Mines
  - Freight—changes in rates—how adjusted
    - When to be made—monthly or otherwise
- Specification
  - Bonus & penalty clause
  - Scale of price per ton
    - Sizing
    - B.T.U. dry coal
    - % ash & fusing point
    - Volatile
    - Fixed carbon
    - Sulphur
    - Nitrogen
  - Inspection clause
- Basis-quality
- Tests for Quality
  - Made by—whom
    - Test to be made—named
      - When
      - Where
      - Methods to be followed
        - Sampling
        - Analysis
    - by whom—seller—purchaser—referee
  - Test Reports
    - Forms
    - Sent to whom

General and Specific Clauses

Seller | Purchaser

PARTIES TO CONTRACT

2. Bidder May Be Present.—Each bidder shall have the right to be present, either in person or by attorney, when the bids are opened.

3. Address of Proposals.—Proposals, in duplicate, must be forwarded to the..................................... postage prepaid. Addressed envelope for mailing is inclosed herewith.

4. Form and Signature.—Proposals must be made in duplicate on the form given herein, and must be signed by the individual, partnership, or corporation making the same; when made by a partnership, the name of each partner must be signed. If made by a corporation, proposals must be signed by the officer thereof authorized to bind it by contract, and be accompanied by a copy, under seal, of his authority to sign.

5. Cash or Certified Check.—The proposals must be accompanied by cash or by certified check drawn payable to the order of the.......... in the amount equal to 2% of the estimated amount involved for the fuel for which bids are submitted, the minimum amount in any case to be $10. This requirement is solely to guarantee, if the award is made on the proposal, that within 10 days after notice is given that an award has been made, the bidder will enter into a contract in accordance with the terms of the proposal and execute a bond for the faithful performance thereof, with good and sufficient sureties as hereinafter required. In the event of the failure of the bidder to enter into contract or execute bond, the cash or check guaranty will be forfeited.

II. Contractor's Bond

6. Sureties.—Each contractor shall be required to give a bond, with two or more individual sureties or one corporate surety duly qualified under the act of Congress approved August 13, 1894, in which the contractor and the sureties shall covenant and agree that, in case the said contractor shall fail to do or perform any or all of the covenants, stipulations, and agreements of said contract on the part of the said contractor to be performed as therein set forth, the said contractor and his sureties shall forfeit and pay to the United States of America any and all damages sustained by the United States by reason of any failure of the contractor fully and faithfully to keep and perform the terms and conditions of his contract, to be recovered in an action at law in the name of the United States in any proper court of competent jurisdiction. Such sureties (except corporate sureties) shall justify their responsibility by affidavit showing that they severally own and possess property of the clear value in the aggregate of double the amount of the above-mentioned forfeiture over and above all debts and liabilities and all property by law exempt from execution; the affidavit shall be sworn to before a judge or a clerk of a court of record or a United States attorney, who must certify of his own personal knowledge that the sureties are sufficient to pay the full penalty of the bond.

7. May be Waived.—If the estimated amount involved in the contract does not exceed the sum of $200, then the bond may be waived with the consent of the department involved.

III. Reservations

8. Rejection of Bids.—The right is reserved by the Government to reject any and all bids and to waive technical defects. Bidders are cau-

tioned against guaranteeing higher standards of quality than can be maintained in delivered coal (this applies especially to bituminous coal and the steam sizes of anthracite), as the Government reserves the right to reject any and all bids, if the Government has information regarding analyses and test results that indicate that higher standards have been offered than probably can be maintained.

9. **Tests.**—The right shall be reserved by the Government to purchase for the purpose of making boiler tests other coal than that herein contracted for, provided the amount so purchased shall not exceed 10% of the estimated consumption during the period covered by this agreement.

10. **Lowest Bids May Not be Considered.**—If it should appear to be to the best interests of the Government to do so, the right is reserved to award the contract for supplying coal at a price higher than that named in a lower bid, or in lower bids.

11. **Failure to Contract.**—If the bidder to whom the award is made shall fail to enter into a contract as herein provided, then the award may be annulled and the contract let to the next most desirable bidder without further advertisement, and such bidder shall be required to fulfill every stipulation expressed herein, as if he were the original party to whom the contract was awarded; provided, however, that such bidder is notified of said award within 60 days after the date on which the bids on this contract were opened. If such notice should not be given within said 60 days, then the acceptance of the award will be optional with the said bidder.

12. **Contracts Non-Transferable.**—No contract can be lawfully transferred or assigned.

13. **Default.**—No proposal will be considered from any person, firm, or corporation in default of the performance of any contract or agreement made with the United States, or conclusively shown to have failed to perform satisfactorily such contract or agreement.

IV. Quantity

• 14. The estimated quantity of coal in......... ....tons of 2,000 pounds to be purchased is based upon the previous annual consumption, but the right will be reserved to order a greater or less quantity, subject to the actual requirements of the service.

V. Delivery

15. **Quantity, Time and Place.**—The coal shall be delivered in such quantities at such times as the Government may direct. (Place of delivery to be stated.)

16. **Rapidity.**—All the available storage capacity of the Government coal bunkers shall be placed at the disposal of the contractor to facilitate delivery of coal under favorable conditions. When an order is issued for coal, the contractor upon commencing a delivery on that order shall continue the delivery with such rapidity as not to waste unduly the services of the Government inspector.

17. **Failure to Deliver.**—After verbal or written notice shall have been given to deliver coal under the contract a second notice may be served

in writing upon the contractor to make delivery of the coal so ordered within a reasonable time, to be determined by the Government official in charge, after receipt of said second notice. Should the contractor for any reason fail to comply with the second request the Government shall be at liberty to buy coal independently of this contract, and for coal so purchased to charge against the contractor and his sureties any excess in price over the price which would have been paid to the contractor had the coal been delivered by him.

18. **Hours.**—The contractor shall be allowed to deliver coal during the usual hours of teaming—that is, between 8 A. M. and 5 P. M.

19. **Weighing.**—(To be stated by whom and where the coal shall be weighed, etc.)

VI. Sampling

20. **Contractor Privileged to be Present.**—The contractor shall have the privilege of having a representative present to witness the collection and preparation of the samples to be forwarded to the laboratory.

21. **Method.**—The samples shall be collected and prepared in accordance with the method given in Appendix A. (See page 24 of this volume.)

VII. Analysis

22. **Laboratory and Method.**—The samples shall be immediately forwarded to the *Bureau of Mines*, Department of the Interior, Washington, D. C., and they shall be analyzed and tested in accordance with the method recommended by the American Chemical Society and by the use of a bomb calorimeter. Such analyses and tests shall be made at no cost to the contractor. The results shall be reported to the *Bureau of Mines* in not more than fifteen (15) days after the receipt of the sample If more than one sample is received from the same delivery, the fifteen (15) days shall date from the receipt of the last sample taken.

VIII. Bituminous and Anthracite Pea and Buckwheat Coal for Power and Heating Plants

DESCRIPTION OF COAL DESIRED

23. **Kind and Quality.**—The coal must be a good coal................ (kind and size to be specified), and must be adapted for successful use in the particular furnace and boiler equipment.

24. **Information to be Supplied by Bidder.**—Bidders are required to specify the coal offered in terms of moisture in the coal "as received," and of ash, volatile matter, sulphur, and British thermal units in "dry coal," such values to become the standards for the coal of the successful bidder. In addition, the bidders are required to give the trade name of the coal offered, the name or other designation of coal bed, name of mine or mines, location of mine or mines (town, county, and State), railroad on which mine or mines are located, and name of operator of mine or mines. This information shall be furnished in spaces provided hereinafter.

NOTE.—Bids not supplying the foregoing information may be considered informal and rejected.

Coal of the description and analysis specified is herein known as coal of the contract grade. Bidders are cautioned against specifying higher

standards than can be maintained, for to do so will result in deductions in price and may result in the rejection of delivered coal or the cancellation of the contract. In this connection it should be recognized that small "mine samples" usually indicate a coal of higher economic value than that actually delivered in carload lots, because of the care taken to separate extraneous matter from the coal in the "mine samples."

25. Considerations.—In determining the award of this contract consideration will be given to the quality of the coal (expressed in terms of moisture in coal "as received," of ash in "dry coal," and British thermal units in "dry coal") offered by the respective bidders and to the operating results obtained with the same and with similar coals on previous contracts or by test, as well as to the price per ton.

26. Bids Subject to Rejection.—Bids may be rejected from further consideration if they offer coals regarding which the Government has information that they possess unsatisfactory physical characteristics or volatile matter or sulphur or ash contents, or that they are unsatisfactory because of clinkering or excessive refuse, or because of having failed to meet the requirements of city smoke ordinances, or for other cause that would indicate that they are of a character or quality that the Government considers unsuited for the storage space or the furnace equipment of the particular contract.

27. Method of Comparing Bids.—In order to compare bids as to the quality of the coal offered, all proposals shall be adjusted to a common basis. The method used shall be to merge the four variables—moisture content, ash content, heating value, and price bid per ton—into one figure, the cost of 1,000,000 British thermal units. The procedure under this method shall be as follows:

(a) All bids shall be reduced to a common basis with respect to moisture by dividing the price quoted in each bid by the difference between 100% and the percentage of moisture guaranteed in the bid. The adjusted bids shall be figured to the nearest tenth of a cent.

(b) The bids shall be adjusted to the same ash percentage by selecting as the standard the proposal that offers coal containing the lowest percentage of ash. The difference in ash content between any given bid and this standard shall be divided by 2 and the price in such bid, adjusted in accordance with the above, multiplied by the quotient. The result shall be added to the above adjusted price. The adjusted bids shall be figured to the nearest tenth of a cent.

(c) On the basis of the adjusted price, allowance shall then be made for the varying heat values by computing the cost of 1,000,000 British thermal units for each coal offered. This determination shall be made by multiplying the price per ton adjusted for ash and moisture contents by 1,000,000, and dividing the result by the product of 2,000 multiplied by the number of British thermal units guaranteed. If the coal is purchased on the basis of 2,240 pounds to the ton, the factor of 2,240 should be used instead of 2,000.

28. Service Test.—After the elimination of undesirable bids, the selection of the lowest bid of those remaining on the basis of the cost per 1,000,000 British thermal units may be considered by the Government as a tentative award only, the Government reserving the right to have practical

service test or tests made under the direction of the *Bureau of Mines*, the results to determine the final award of contract. The interested bidder or his authorized representative may be present at such test.

CAUSES FOR REJECTION

29. **Coal Subject to Rejection.** —It is understood that coal containing 3% more moisture, or 4% more ash, or 3% more volatile matter, or 1% more sulphur, or 4% fewer British thermal units than the specified guarantees as to the standards for the coal hereunder contracted for, or coal furnished from a mine or from mines other than herein specified by the contractor, unless upon written permission of the Government, shall be considered subject to rejection, and the Government may, at its option, either accept or reject the same. Should the Government have consumed a part of such coal subject to rejection, such consumption shall not impair the Government's right to cause the contractor to remove the remainder of the delivered coal subject to rejection.

30. **Cancellation of Contract — Open Market Purchases.** — It is agreed that if the contractor shall furnish coal in three consecutive deliveries, or in case more than 20% of the coal delivered to any date during the life of this contract shall contain 3% more moisture, or 2% more ash, or 3% more volatile matter, or 1% more sulphur, or 2% fewer British thermal units than the specified guaranties as to the standards for the coal hereunder contracted for, or if coal is furnished from a mine or from mines other than herein specified, unless upon the written permission of the Government, then this contract may, at the option of the Government, be terminated, or the Government may, at its option, purchase coal in the open market until it may become satisfied that the contractor can furnish coal equal to the standards guaranteed, and the Government shall have the right to charge against the contractor any excess in price of coal so purchased over the corrected price that would have been paid to the contractor had the coal been delivered by him.

31. **Removal of Rejected Coal.** —The contractor shall be required to remove, without cost to the Government, within 48 hours after notification, coal that has been rejected by the Government. Should the contractor not remove rejected coal within the said 48 hours, the Government shall then be at liberty to have the said coal removed from its premises and to dispose of such coal by sale, as the Government shall elect. The proceeds from such sale, less all costs incidental to its removal and to the sale, shall be paid over to the contractor.

PRICE AND PAYMENT

32. **Determination of Price.** —The Government hereby agrees to pay the contractor within thirty (30) days after the completion of an order or delivery for each ton of 2,000 pounds of coal delivered and accepted in accordance with all the terms of this contract, the price per ton determined by taking the analysis of the sample, or the average of the analyses of the samples if more than one sample is analyzed, collected from the coal delivered upon the basis of the price herein named, adjusted as follows for variations in heating value, ash content, and moisture content from the standards guaranteed herein by the contractor. (On orders of 50 tons or less, sampling is discretionary with the Government and if no samples are taken, the bid price is paid.)

(*a*) **Heat Unit Adjustment.** —Considering the coal on a "dry-coal" basis, no adjustment in price shall be made for variations of 2% or less

in the number of British thermal units from the guaranteed standard. When the variation in heat units exceeds 2% of the guaranteed standard, the adjustment shall be proportional and shall be determined by the following formula:

$$\frac{BTU \text{ delivered coal ("dry-coal" basis)}}{BTU \text{ ("dry-coal" basis) specified in contract}} \times \text{bid price} = \text{price resulting}$$

for BTU variation from the standard

The adjusted price shall be figured to the nearest tenth of a cent.

As an example, for coal delivered on a contract guaranteeing 14,000 British thermal units on a "dry-coal" basis at a bid price of $3 per ton, showing by calorific test results varying between 13,720 and 14,280 British thermal units, there would be no price adjustment. If, however, by way of further example, the delivered coal shows by calorific test 14,350 British thermal units on "dry-coal" basis, the price for this variation from the contract guaranty would be, by substitution in the formula:

$$\frac{14,350}{14,000} \times \$3 = \$3.075$$

(b) **Ash Adjustment.**—No adjustment in price shall be made for variations of 2% or less below or above the guaranteed percentage of ash on the "dry-coal" basis. When the variation exceeds 2%, the adjustment in price shall be determined as follows:

The difference between the ash content by analysis and the ash content guaranteed shall be divided by 2, and the quotient shall be multiplied by the bid price in dollars per ton, and the result in cents per ton shall be added to or deducted from the BTU adjusted price or the bid price, if there is no BTU adjustment, according to whether the ash content by analysis is below or above the percentage guaranteed. The adjustment for ash content shall be figured to the nearest tenth of a cent.

As an example of the method of determining the adjustment in cents per ton for coal containing an ash content varying by more than 2% from the standard, consider that coal for which the above-mentioned heat unit adjustment is to be made has been delivered on a contract guaranteeing 10% ash, and shows by analysis an ash content of 7.50%. The adjustment in price would be determined as follows:

The difference between 10 and 7.50, which is 2.50, would be divided by 2, and the quotient of 1.25 multiplied by $3, resulting in an adjustment of 3.7 cents per ton, which in this case would be an addition. The price after adjustment for the variations in heating value and ash content would be $3.075 plus $0.037, or $3.112.

(c) **Moisture Adjustment.**—The price shall be further adjusted for moisture content in excess of the amount guaranteed by the contractor, the deduction being determined by multiplying the price bid by the percentage of moisture in excess of the amount guaranteed. The deduction shall be figured to the nearest tenth of a cent.

As an example, consider coal for which the above-mentioned heat unit and ash adjustments are to be made, as having been delivered on a contract guaranteeing 3% moisture, and that the coal shows by analysis 4.50% moisture; then the bid price, $3, would be multiplied by 1.50 (representing excess moisture), giving 4.5 cents as the deduction per ton. The price to be paid per ton for the coal would then be $3.112, less $0.045, or $3.067.

33. Partial Payment.—If coal on visual inspection by the Government inspector appears to be acceptable coal, the Government shall have the right, immediately on the completion of an order, to make payment on 90% of the amount of the bill, based on the tonnage delivered and the bid price per ton. The 10% withheld is to cover any deduction on account of the delivery of coal that on analysis and test is subject to an adjustment in price. If the 10% withheld should not be sufficient to cover the deduction, then the amount due the Government may be taken from any money thereafter to become due to the contractor, or may be collected from the sureties. Because of the distance of the points of delivery from the laboratory, requiring several days for the transmittal of samples and the return of analytical report, because of loss of the original sample, necessitating the forwarding of the reserve sample, or for any other reason that would result in delayed payment, should such be withheld until receipt of analytical report, the Government may, as circumstances in its opinion warrant, exercise the foregoing right.

IX. Anthracite Coal—Domestic Sizes

DESCRIPTION OF COAL DESIRED

34. Character and Quality.—The coal must be best quality, fresh-mined, anthracite, and it must be well screened, practically free from dirt, must not contain undue percentages of moisture, slate, or bone, or of coal of smaller sizes, and must equal in quantity and preparation the best anthracite coal produced.

35. Information to be Supplied by Bidder.—The bidder shall be required to give the trade name of the coal offered, the name or other designation of coal bed or beds, the name of mine or mines producing the coal, location of mine or mines (town, county, and State), the name and address of the operator of mine or mines, and the railroad upon which the mine or mines are located, this information to be given in spaces provided hereinafter.

AWARD

36. Consideration.—In determining the award of the contract consideration shall be given to the results obtained with coals furnished on previous Government contracts by the respective bidders, as well as to the price per ton.

CAUSES FOR REJECTION

37. Unsatisfactory Coal.—If the percentage of bone, dirt, slate, or smaller sizes in a delivery exceeds the percentage required by the best preparation, or if the given coal fails to give satisfactory results because of excessive clinkering or excessive ash-pit refuse, it shall be subject to rejection, and payment may not be made for the remaining coal, and the Government shall have the right to cause the contractor to remove such coal at no cost to the Government. The Government may then purchase coal in the open market and make charge against the contractor for the excess in cost of coal so purchased.

38. Ash Deduction.—If it is impracticable for the Government to cause the contractor to remove coal that produces excessive ash-pit refuse, samples may be taken during the consumption of such coal, provided not more than 50% of the delivery had been consumed, and if on analysis the ash content on the "dry coal" basis is equal to or greater than the follow-

ing percentages for the respective sizes of coal, ten (10)% of the price of the delivery in question shall be deducted from any money due or that may thereafter be due the contractor:

Size of Coal	Ash in "Dry Coal," Per Cent.
Furnace	14
Egg	15
Stove	16
Chestnut	18

39. **Unacceptable Coal.**—The Government inspector will not accept coal if, in his opinion, on visual inspection, it is subject to rejection, or if it contains an undue percentage of moisture, and he shall have the right to refuse to accept coal from a source other than that specified by the bidder, unless the contractor shall have received permission from the Government to substitute said coal.

40. **Cancellation of Contract.**—If the contractor furnishes coal in three consecutive deliveries, or in case 20% of the amount of the coal delivered to any date during the life of the contract, is, in the opinion of the Government, subject to rejection, then the contract may, at the option of the Government, be terminated by written notice to the contractor to that effect.

PRICE AND PAYMENT

41. Payment shall be made within thirty (30) days after the completion of an order and shall be based on the contract price, provided the coal is not subject to rejection.

X. Information to Be Supplied by Bidders

42. The following spaces should be filled in by the bidder for each bid, for if the information called for is not supplied, the proposal may be regarded as informal

(Bidders are cautioned against specifying higher standards than can be maintained, for to do so may result in the bid being rejected, or may result in rejection of delivered coal or cancellation of the contract and the Government purchasing coal in the open market and charging against the contractor the difference in cost. See paragraphs 8, 29, 30, 31.)

....
(To be signed by office issuing proposals.)

The undersigned agree . to furnish to the............................
the coal described below, in tons of 2,000 lb. each and in quantity as may be required during the fiscal year ending June 30, 192.., in accordance with the foregoing specifications; the coal to be delivered in such quantities and at such times as the Government may direct.

(a) Kind and size of coal......................................
(b) Commercial name of coal....................................
(c) Name of mine or mines.....................................
(d) Location of mine or mines (town, county, and State)..........
(e) Name or other designation of coal bed or beds...............
(f) Railroad on which mine or mines are located.................
(g) Name of operator of mine or mines..........................
(h) Percentage of moisture in coal "as received"................

   (*i*)   Percentage of ash in "dry coal".................................

   (*j*)   Percentage of volatile matter in "dry coal"....................

   (*k*)   Percentage of sulphur in "dry coal"...........................

   (*l*)   British thermal units per lb. of "dry coal"....................

   (*m*) Additional description of coal deemed of importance by the bidder ....

   (*n*)   Price per ton of 2,000 lb. for delivery (for bituminous coal and for pea and buckwheat sizes of anthracite this price is understood to be the bid price per ton, see paragraph 32 for method of determining price for delivered coal) ....

NOTE.—The information called for under *h, i, j, k,* and *l* is not required for bids on the domestic sizes of anthracite coal, that is, furnace, egg, stove, and chestnut.

The rules for sampling given on pages 24 to 29 are attached as an appendix to these specifications.

WASHING OF COAL

Many coal seams, particularly in the Pacific Northwest, contain "partings" of ash-forming impurities varying in thickness from ¼ in. to several feet in the same seam within a distance of a few hundred yards. The specific gravity of the clean coal particles is about 1.30 for sub-bituminous coal, 1.32 for bituminous coal, and 1.43 for anthracite, while that of the impurities ranges from 1.40 for some bony coals to 2.70 for the heaviest shales. Such coal can often be advantageously "washed" on a commercial scale, the processes consisting of a rather rough classification of the individual particles into two or more groups according to their specific gravities. While other factors than ash content affect the specific gravity, the effect of the latter is sufficiently marked to enable the operator so to make the division that the lighter portion constitutes an improved fuel of low ash, with a minimum loss of combustible in the rejected portion. In a jig the material rests on a stationary screen with a slight pitch, while water from a trough below the screen is made to surge up and down and to sort the coal according to relative density, the upper layers being withdrawn by gates adjustable to give any desired proportion. Washing tables similar to ore concentrators are used with fine coal, and contain closely-spaced riffles or strips projecting slightly above the level of the table, parallel to the feed side and filling the triangular space bounded by the side opposite the feed, a side adjacent to it, and a diagonal of the rectangular table. Water flows continually over the table, which is repeatedly jerked so that the lighter particles are carried along in suspension in the water, while the heavy "concentrate" (refuse) escapes at the side of the table which does not contain the riffles.

While the groups formed in a commercial water-agitation system will overlap somewhat, exact laboratory tests for specific gravity of washed coal or coal to be washed are made by *float-and-sink* tests in a heavy liquid, such as zinc chloride solution, which can be varied from 1.00 to 1.84 specific gravity. When a sample is placed in a liquid of some chosen gravity, the particles lighter than the liquid float, and those which are heavier sink; in fact if inexpensive liquids were available, this method could be used for actual coal beneficiation as well as for tests. *E. R. McMillan* and *B. M. Bird* describe the standard test method developed by the *Bureau of Mines* and the *University of Washington Experiment Sta-*

tion. Coal smaller than 3 in. is screened into six sizes, using round-hole screens of 1½, ¾, ⅜, ³⁄₁₆ in. diameter, and 20-mesh screens. Samples of each size are then tested in liquid of 1.70, 1 55, 1.45 and 1.35 specific gravity. A tank 37x25x18 in. is used, with a pan which fits down into it, having a 70-mesh screen bottom to hold the "sink," and provision for sliding in a flexible 22-mesh screen between the float and the sink, after the pieces have come to equilibrium, so that the two groups can be kept separate. Each is then weighed, crushed and analyzed for ash content, a tabulation being made as in the following:

SCREEN-SIZING TESTS OF RAW COAL

Name	Screen (round holes)	Wt. lb.	Wt. %
Lump	Over 3-inch	....	....
Egg ...	Through 3-inch over 1½-inch .	709	25 4
Nut ..	Through 1½-inch, over ¾-inch	457	16.4
Pea	Through ¾-inch, over ⅜-inch '.	728	26.1
Buckwheat	Through ⅜ inch, over ³⁄₁₆-inch ..	198	7.1
Bird's-eye	Through ³⁄₁₆-inch, over 20-mesh* .	497	17.8
Fines .. .	Through 20-mesh*	201	7.2
	Total sample	2790	100 0

*Wire mesh screen.

TABULATION OF FLOAT-AND-SINK TEST DATA

Product	Specific gravity	Weight %	Ash %*	Cumul. wt %	Cumul. ash %*
	Under 1 30	15 8	4 1	15 8	4.1
	1 30 to 1.35	27 2	9 0	43.0	7.2
Raw egg—	1 35 to 1.40	15.3	16 5	58.3	9 6
(Through 3-inch,	1 40 to 1.45	6 9	23 1	65.2	11 1
over 1½-inch)	1 45 to 1 50	6 3	29 3	71.5	12.7
Ash 24.8% *	1 50 to 1 55	5.4	35 0	76 9	14 2
Total sample—403 lbs.	1 50 to 1 70	7 5	43.9	84 4	16.9
	Over 1 70	15 6	71 5	100.0	25 4
	Under 1 30	30 3	3.3	30.3	3.3
	1.30 to 1 35	27 3	7 8	57.6	5.4
Raw buckwheat—	1 35 to 1 40	11 4	15.6	69 0	7.1
(Through ⅜-inch,	1.40 to 1.45	5 9	21.9	74 9	8.3
over ³⁄₁₆-inch)	1 45 to 1.50	5 0	27.5	79.9	9.5
Ash 18 7%.	1 50 to 1 55	3.4	33.7	83 3	10.5
Total sample—32 lbs.	1.55 to 1.70	6 5	43 3	89 8	12.9
	Over 1 70	10 2	71 3	100.0	18.8

*Moisture-free basis.

For a given size, the weight column gives the % falling between the various specific gravity limits; the ash column gives the % ash in the individual sample, which is greatest, naturally, in the high-gravity group. The cumulative weight % for each line is the sum of the weight % down to and including the line in question. Each weight % is multiplied by its ash %, the sum of such products up to and including any given line is divided into the cumulative weight % for the same line, to give the cumulative ash %. The last two columns are plotted against each other, as in Fig. A, each point being labeled with the higher gravity limit. For instance, the table and chart both indicate that for the egg size, 58.3% by weight of the total is under 1.40 in gravity, and that 9.6% of the material under 1.40 specific gravity is ash. The final cumulative ash % in the last column should check reasonably well with the original ash determination for the size. If, in commercial operation, 10% is the maximum permissible ash in the washed coal, the intersection of the vertical 10% line with the
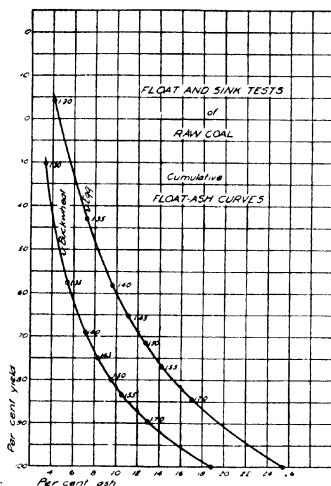
A. METHOD OF PLOTTING FLOAT-AND-SINK TESTS
—*Univ. of Wash. Exp. Sta.*

curves shows that the maximum % of the coal which can be recovered and marketed is 60% for the egg size and 81.5% for the buckwheat. The float-and-sink test for coal finer than 20-mesh is similar in principle to the above; the solution used is carbon tetrachloride mixed with benzene or bromoform, according to whether the desired specific gravity is above or below 1.59. The separation is made in 2-liter bottles, and the float is removed by suction through a bent glass tube which is moved over the surface of the liquid.

Refuse from a commercial washing plant will contain a certain amount of float and the washed coal a certain amount of sink, although a good machine should recover 90% of the recovery theoretically possible with a chosen ash content. After determining on this basis the "permissible bath" for a particular product, that is, the specific gravity at which separation is to be made, the success in approximating the desired separation can be estimated by making float-and-sink separations for the chosen specific gravity, of the raw feed, the washed coal, and the refuse, without ash determination. *Drakeley* gives the following formulas for the efficiency of a commercial coal washer:

$$\text{Qualitative efficiency} = \frac{100 \times (\text{washed coal float} - \text{raw coal float})}{100 - \text{raw coal float}}$$

$$= \frac{100 \times (\text{raw coal sink} - \text{washed coal sink})}{\text{raw coal sink}}$$

$$\text{Quantitative efficiency} = \frac{100 \times \left(\text{raw coal float} - \dfrac{\% \text{ refuse} \times \text{refuse float}}{100}\right)}{\text{raw coal float}}$$

$$\text{General efficiency} = \frac{\text{Qualitative efficiency} \times \text{quantitative efficiency}}{100}$$

in which washed float $=$ % of float in the washed coal etc.

$$\% \text{ refuse} = \frac{100 \times (\text{washed coal float} - \text{raw coal float})}{\text{washed coal float} - \text{refuse float}}$$

The qualitative efficiency is the ratio of actual improvement in the washed coal to the maximum possible indicated by the float-and-sink test, and would be the true efficiency if no float or good coal was lost in the refuse.

The numerator is the float actually recovered minus that which the test showed to be present in the raw coal, and indicates how much refuse material has been removed, while the denominator shows how much was meant to be removed. The quantitative efficiency is the % of float in the feed that is recovered in the washed coal, and the general efficiency is the product of the two. The same raw feed handled with two different jig adjustments gave the following results:

ADJUSTMENT A

Raw coal float,   80%
Washed coal float,   95%
Refuse float,   12%

Percentage refuse $= 100 \times \dfrac{95 - 80}{95 - 12} = 18\%$

Qualitative efficiency $= \dfrac{100 \times (95 - 80)}{100 - 80} = 75.0\%$

Quantitative efficiency $= \dfrac{100 \times (80 - \dfrac{(18 \times 12)}{100})}{80}$
$= 97.3\%$

General efficiency $= \dfrac{75.0 \times 97.3}{100} = 73.0\%$

ADJUSTMENT B

Raw coal float,   80%
Washed coal float,   97%
Refuse float,   16%

Percentage refuse $= 100 \times \dfrac{97 - 80}{97 - 16} = 21\%$

Qualitative efficiency $= \dfrac{100 \times (97 - 80)}{100 - 80} = 85.0\%$

Quantitative efficiency $= \dfrac{100 \times (80 - \dfrac{(21 \times 16)}{100})}{80}$
$= 95.8\%$

General efficiency $= \dfrac{85.0 \times 95.8}{100} = 81.4\%$

The washed coal shows an improvement in quality under adjustment B, but the refuse carries a greater percentage of float than it does with adjustment A, and it requires the above calculation to show that B is the more desirable adjustment. With apparatus making more than one product, each compartment should be considered as a separate jig. A sample is taken of the overflow from the first compartment to the second, tested for both specific gravities, and taken as the "washed coal" for the first compartment and the "feed" for the second compartment. The Drakeley formula assumes that the float in the feed, washed coal and refuse is of the same ash content, but the float coal in a refuse product is nearly always slightly lower in specific gravity than the "permissible bath," and therefore much higher in ash than the float in the washed coal. This inconsistency in the formula tends to make the calculated efficiency of an operation low. A commercial washer treating coal 1 in. and finer should be 75% efficient, 65% has been reached with coal 2½ in. and finer, while 85% has been obtained with a laboratory jig on closely-sized feed.

William Strain describes a method used for reclaiming a sludge pond consisting of sub-bituminous buckwheat coal which was too gummy and high in incombustible for use by pulverizing without cleaning. Sand and larger pieces of bone and shale had settled at the inlet to the pond, the rest of the pond was more or less stratified, with mud at the overflow containing streaks of clean coal from $\frac{3}{16}$ in. downward in diameter. The material was "dissolved" and sluiced by water under pressure, overcoming the effect of segregation and affording a nearly uniform feed to the *Deister-Overstrom* coal washing table, so that the angle of adjustment could be kept uniform for long periods. The raw material contains 28 to 30% ash, which is reduced to 16 to 18% by the washing, with entire

elimination of sand, clay and shale. This is satisfactory for use in the Seattle central heating plant, although it would be possible to reduce the ash in the product to 10% without losing an appreciable amount of clean coal in the refuse.

G. R. Delameter describes the effect of screening coal into two size-groups, washing one portion with water and mixing the unwashed portion with it. The machine used was a 6-ft. electrically vibrated screen, with a total screen area of 30 sq ft, a power consumption of 1 HP, and a capacity of 80 to 110 tons per hour, depending on initial moisture content. The frame is rigid, but the screen cloth receives 1800 vibrations per minute, and is also "bumped" periodically. Each vertical line in the chart represents the effect of operating with a particular screen, washing all coal which is retained on that screen, by-passing the smaller particles and mixing them, unwashed, with the washed coal. It will be noticed that the minimum sulphur in the final mixed product is obtained by using the 20-mesh screen, and the minimum ash with the 10-mesh screen. The finer the mesh, the more coal is washed, and the smaller the total % yield, down to 86.12% if all the coal is washed. For striking a balance in the reduction of ash and sulphur, 14-mesh would be suitable, but the coal from the Pennsylvania plant where the tests were made was sold for the manufacture of metallurgical coke, and 1 20% sulphur was permissible, so that 4-mesh screens were finally adopted, permitting the recovery of 93% of the raw coal as against 88% with 14-mesh. When all the coal was washed, twelve jigs, three settling tanks with Luhrig dewatering elevators and
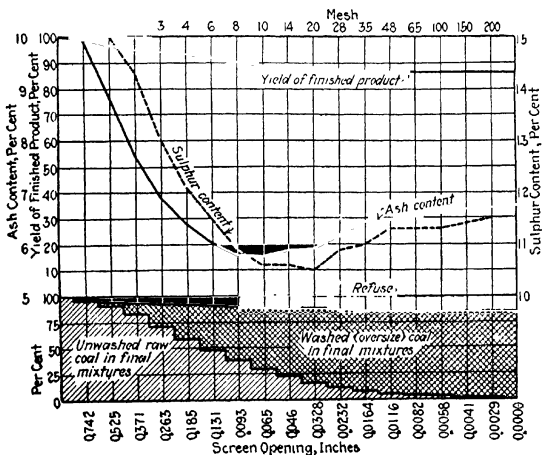
EFFECT OF SCREENING AND WASHING COAL—*Coal Age*

three Elmore centrifugal coal driers were required, and this was cut down to six jigs, one tank and one drier.

The *Bureau of Mines* ran evaporative tests and made analyses on 26 different coals, both raw and washed The washed coals either burned more freely or seemed to burn more rapidly than the raw coal. The percentage of capacity developed was somewhat greater with the washed than with the unwashed coal. The averages of the results of 26 tests are given below:

	Raw	Washed
Moisture in coal as fired..	. 7 48	8 06
Ash as fired....	12 48	7.84
Ash in dry coal	13 54	8 58
Sulphur in coal as fired .	2 99	2 24
Sulphur in dry coal...	3.29	2.50
Clinker in refuse..	.42	41
Volatile in combustible.	40.50	40 82
% rated capacity..	89 9	96 6
Efficiency	66 95	64 82
Black smoke, %...	18 1	26 3
Carbon monoxide	.12	.19
Unaccounted for loss.	.. 9.41	12.40

In the washed coal a small amount of the sulphur had been removed, and a considerable amount of the ash The washed coals gave a lower efficiency, and burned with a much greater amount of smoke.

The *Trent process* for **oil-cleaning** of coal is based on the phenomenon of differential wetting, as in the froth flotation of ores. A mixture of water and pulverized coal is agitated with a non-viscous oil in an amount equal to 30% of the weight of the coal, which causes the carbonaceous material to form with the oil a floating amalgam of de-ashed plastic fuel, while the mineral matter remains suspended in the water. The loss of oil in the refuse and water is negligible, while the oil in the amalgam can be totally or wholly reclaimed, depending on whether powdered fuel, coke or briquettes are desired. Laboratory tests by the *Bureau of Mines* show that it is possible to cut down the ash in the product to one-fourth to two-thirds of what it was in the raw fuel, and that, except when operating with refuse coal, considerably over 95% of the combustible is recoverable. Pyrite particles tend to become wetted by oil and to go into the amalgam, so that with bituminous coals the percentage of sulphur remains about the same before and after cleaning, and preliminary water washing should be used with high-sulphur coals. The process permits wet grinding of the coal, which is easier than dry grinding, but grinding below 200-mesh does not give sufficiently greater ash reduction to pay for its cost. Table I. shows the results of field tests by the *Bureau* on the standard machine of *Minerals Separation, Ltd* , and it was also found that with a *Ruth* machine, corresponding to the sub-aerated type of the same concern, much less oil could be used to get a satisfactory loaded froth.

Table II. shows the way in which a coal tends to divide into several products, the cleanest being floated first. The first four were quite bony and the last was fairly clean without so much bone.

TABLE I. TESTS ON OIL CLEANING OF COAL

Product Treated	Source	% Ash In Feed	% Ash In Concentrate	% Recovery Combustible	Oil Consumed Kind	Oil Consumed Lb. Per Ton
Sub-bituminous table middling	Mendota, Wash.	47.85	25.66	71.2	Pine oil (steam distilled)	1.5
Sub-bituminous run-of-mine	Renton, Wash.	28.75	23.75	44.9	Coal tar, pine oil	2.0
Sub-bituminous washery sludge	Renton, Wash.	19.38	10.66	34.6	Coal tar, hardwood oil	3.0
Sub-bituminous fine screenings	Bellingham, Wash.	22.65	13.30	54.1	Hardwood creosote	2.0
Sub-bituminous run-of-mine	Issaquah, Wash.	33.25	22.38	33.6	Kerosene, pine oil	8.0
Sub-bituminous washery sludge	Issaquah, Wash.	29.35	17.10	11.8	Kerosene, pine oil	2.0
Coking bituminous, table middling	Palmer, Wash.	30.01	20.00	76.7	Pine oil	0.5
Coking bituminous, run-of-mine	Carbon Co., Utah	6.00	4.00	61.4	Pine oil	0.7
Coking bituminous, run-of-mine	Ladysmith, B. C.	8.60	4.95	73.7	Pine oil	0.25
Non-coking bituminous, run-of-mine	Roslyn, Wash.	17.80	9.98	56.1	Pine oil	0.6
Non-coking bituminous, run-of-mine	Roslyn, Wash.	24.15	13.43	72.6	Kerosene oil	1.0
Non-coking bituminous, run-of-mine	Carbonado, Wash	18.65	10.37	60.0	Pine oil	0.8
Coking bituminous, run-of-mine	Carbonado, Wash.	9.50	7.33	52.0	Pine oil	0.8
Semi-anthracite, run-of-mine	Carbonado, Wash.	8.02	4.38	64.2	Pine oil	0.8
Coking bituminous, run-of-mine	Wilkeson, Wash.	14.38	10.73	60.0	Pine oil	0.5
Coke (beehive)	Wilkeson, Wash.	18.50	16.10	66.8	Pine oil	0.4
Coke (beehive)	Fairfax, Wash.	23.65	18.00	60.8	Pine oil	1.0

TABLE II. PRODUCTS OF OIL-CLEANING

Coal Treated	Source	Feed % Ash	First Concentration		Second Concentration		Tailing	
			Weight %	Ash %	Weight %	Ash %	Weight %	Ash %
Sub-bituminous	Renton, Wash...	19 4	32 0	10 7	35.0	14 0	33.0	33.2
Sub-bituminous	Bellingham Wash.	22.7	70 0	13 5	15.0	26.9	15.0	57.0
Bituminous....	Roslyn, Wash..	17 8	33 0	10.1	49 0	11 4	19 0	51.0
Bituminous....	Roslyn, Wash.	17 9	77 0	12.4	19 0	30 1	4.0	73.3
Coking bituminous	Carbonado Wash.	8 0	61 6	4 4	34 1	9 8	3.4	62.5

One method to dispose of the concentrate would be to dry it and pulverize it further. The British concern referred to recommends briquetting it, using an amount of pitch equal to 5 to 7% of the dry weight of the coal, mixed with some cresol and kerosene. The binder may be introduced into the froth concentrate in the liquid state, or with coals containing no bone can be used to cause the flotation. It can be used in coke ovens by partially drying it in a rotary drier.

The general conclusions reached, in connection with this work and that of the British concern referred to, were that:

(1) Due to unexplained difficulties, very finely ground coal slime does not concentrate well by flotation and the process is limited to the treatment of the more granular material. Whereas the finer sizes should give a cleaner concentrate, they actually give a dirtier one.

(2) Coals with a bright luster have been found to concentrate more cleanly than dull coals.

(3) There are indications that cleaner flotation is obtained when the coal is broken into sharp angular fragments than when ground down to rounded pieces.

(4) While in general the coals of higher rank, like the semi-anthracite and the coking coals, are more amenable to flotation, this is not essentially so, as some of the sub-bituminous coals have been successfully floated.

(5) The mode of occurrence of the ash in the coal is most highly important, as it has been found that most of the ash present in bony coal and bone coal cannot be liberated by the finest attainable commercial grinding.

(6) The free clean ash can be left in the flotation tailing and the remainder of the coal can easily be floated away from it.

(7) The cleanest coal is the most easily floated, provided the flotation oil consists of a poor frother with no collector and a sub-aeration or pneumatic flotation machine is used.

(8) Bone coal floats almost as easily as clean coal, but will require the use of a better frothing oil and some collector for complete extraction.

(9) Bituminous shale is somewhat less easily floated than bone coal.

(10) For grading a coal by flotation into clean coal, bone, bituminous shale and free ash, careful control and the use of differential flotation methods is necessary.

(11) Flotation tests on removing the ash from finely ground coke have not shown much success.

F. A. Brackmann describes a magnetic process used in Germany for the recovery of combustible from refuse. A stationary magnet consisting of from one to four fields is placed within a revolving drum, with a corresponding number of channels leading down from a shaking feeder.

Each field is divided into three parts, a strong one on the upper side, the strongest in the middle to counteract the centrifugal force, and a weaker below. The iron pyrite in the coal which is actually burned is present in the refuse as ferric oxide, bound with silicates and lime, and the slag containing it is held to the drum by the magnetic field and carried to the weak section, where it drops off, while the non-magnetic good coal and coke are thrown off at a tangent and slide down an iron baffle sheet. Portable plants of from 1 to 1¼ tons per hr. capacity require about 1.5 HP. for operating the elevator, shaking feeder and revolving drum, and 1 kw. of D-C for the field. Plants up to 20 tons per hr. are equipped with a grate, crusher and sifting drum for feeding the refuse to the separator. More than 80% of the combustible in the refuse is recovered, and the extracted fuel can be burned with an efficiency of from 70 to 80% of that obtained with the original coal.

MAGNETIC SEPARATOR FOR
RECOVERING COMBUSTIBLE—
Iron Age

STORAGE OF COAL

The storage of coal is made necessary because of market conditions, the danger of labor difficulties at the mines and on the railroads, and shortage of transportation facilities.

F. G. Tryon and *W. F. McKenney* stated in 1923 that, counting interest on capital tied up in coal and equipment, overhead expense and degradation, the cost of coal storage was 50 cents to $1.00 per ton, which is often justified by saving in price through purchasing when coal is cheap, and insurance against shutdown of plant. They state that for the individual consumer to profit from a storage policy, he should store more than his neighbor, so that he can stay out of the market when the neighbor is in distress and is bidding up the price. He should also keep on buying so long as he can get coal at a moderate price, falling back on the stock pile only in the last stages of a suspension of mining or after work has been resumed.

Anthracite is the best coal for storing. It is not subject to spontaneous combustion, and can therefore be stored in unlimited amounts in one pile. Bituminous coal may ignite, or suffer disintegration.

The storage of coal under water unquestionably preserves its heating value, but it necessitates the firing of wet coal. Illinois and Wyoming coals retain 5% to 15% moisture, even after draining. High-grade Eastern coals retain only 2% to 3%. This makes no difference where the fireman

is allowed to wet down the coal anyway. The submerging of stored coal is an absolute preventive of spontaneous combustion, and on that score may be justified. Unless the storage period is more than a year, there is no reason for storing under water to conserve the heat value.

Two changes may take place in coal, first the oxidation of the inorganic matter, such as pyrites; causing a marked increase in volume, sometimes an increase in weight, and marked disintegration; second, the oxidation of the organic matter of the actual coal. This cannot be detected by the eye, but leads to the loss of heating value through the oxidation of hydrogen and carbon and the absorption of oxygen by the unsaturated hydrocarbon. According to *Steam*, the loss may run up to 10%, when stored in air, and 8¾% when stored under water.

The *University of Illinois* ran extensive experiments on the weathering of coal. The most rapid loss occurred during the first week or ten days. It was slow thereafter, and continued indefinitely. The loss was greater in small coal, due to the proportionately greater exposed surface. The loss in covered bins was substantially the same as in open bins. "In coals tested, 1% is about the average loss for the first week, and 3% to 3½% will cover the loss for a year, although in some cases the loss was found to be as high as 5% in a year." *Hays* says these figures are in excess of what should be expected in commercially stored coal.

The *Bureau of Mines* found the loss in different bituminous coals due to differences of storing to be as follows:

New River coal: The loss in heating value in one year, stored in the open, was less than 1%. The loss in heating value in two years in the open was 1.85%. The loss in heating value in one year, submerged, practically nothing. There was no slacking of lumps in run-of-mine. Fresh and salt water were equally good for storing coal.

Pocahontas: The loss in calorific value in one year when stored in the open was 0.4%. There was little slacking.

Pittsburgh coal (gas coal): There was no measurable loss in calorific value in one year, even in the top six inches.

Wyoming coal: Loss in calorific value in three months 2.5%, 5.3% in 2¾ years. There was very bad slacking at the surface, but it only penetrated 12 or 18 inches.

The loss in one year by weathering Illinois coal was between 1% and 3%.

The *BTU* content is decreased very little by storage, but it is generally believed that stored coal burns less freely than fresh coal, unless a thinner bed is used on the grate, and that the coking qualities of most coals are decreased. Some of the loss in *BTU* content may be due to dirt scooped up in reclaiming. The deterioration of coal stored under
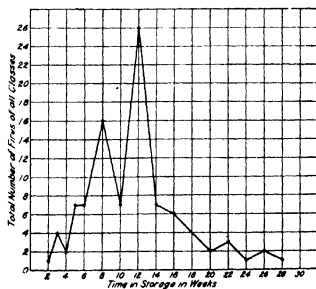
TIME OF STORAGE OF COAL BEFORE DISCOVERY OF FIRE.—*Ill. Exp. Sta.*

water is negligible, and the coal absorbs very little extra moisture. The accompanying figure, based on study of Chicago coal-pile fires, shows that the greatest fire risk is in the first three or four months of storage, during which time special care should be taken to watch the pile.

The volatile matter does not of itself increase the liability of coal to spontaneous heating. Two thousand letters were sent out by the *Bureau of Mines* to large coal consumers. In 1200 replies, 260 reported spontaneous combustion, and 220 gave the name of the coals, which were classified as follows:

    95 semi-bituminous, low volatile Appalachian coals.
    70 higher volatile, Appalachian coals.
    55 Western and Middle Western coals.

This shows that there was no reason for especial confidence in low volatile or smokeless coals for safety in storage.

High volatile Western coals usually are very liable to spontaneous heating, but they owe this property to their chemical nature. The oxygen content appears to bear a direct relation to the avidity with which coal absorbs oxygen. High oxygen coals absorb oxygen readily, and have a marked tendency to spontaneous combustion.

The effect of moisture on spontaneous combustion is a question on which opinions differ. *Richter* says that in the laboratory moist coal oxidizes more rapidly. In no instances of spontaneous combustion investigated by the *Bureau of Mines* could it be proved that moisture had been a factor.

Whereas there is no conclusive data as to the effect of the sulphur content upon storing coal, laboratory experiments by the *Bureau of Mines* showed that there was practically no reduction in the total sulphur in the coal when air at 120° C. was passed through it, although sufficient heat was developed to bring the coal almost to the ignition point. Indications are that sulphur content contributes very little to spontaneous heating.
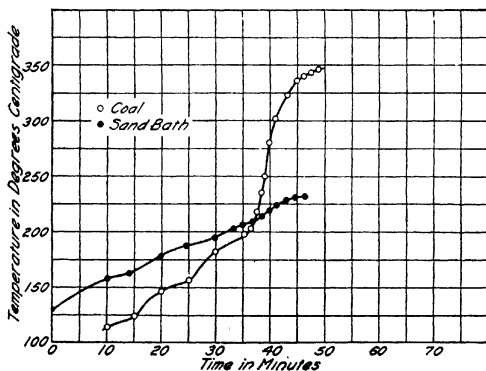
HEATING CURVES FOR DETERMINING IGNITION TEMPERATURE—
Ill. Eng. Exp. Sta.

It is difficult to determine a definite **ignition temperature** for coal.

Wheeler used a method of investigation in which the coal was confined in a test-tube surrounded by an electrically heated sand bath. Air was drawn through the tube, and temperatures of sand and coal observed by thermometers. On plotting the temperature curves, the point where the coal begins to heat more rapidly than the sand could be taken as the ignition temperature, but for definiteness, the point where the coal and the outside-heat curves cross (205° C. in the accompanying chart) is taken as the "relative ignition temperature." This point is of course dependent on the particular apparatus used, but was seen to vary with oxygen content of the fuel as follows:

RELATIVE IGNITION TEMPERATURES FOR VARIOUS OXYGEN CONTENTS

Oxygen Content, % ..	11 1	11.1	11 1	10.6	10 5	10 3	9 9	9.9
Rel Ig. Temp.,° C. ..	165	165	167	177	176	177	177	179
Oxygen Content. % ..	9.9	9 5	9 2	8 8	8 8	8 7	8 6	8.5
Rel. Ig Temp , ° C.	179	178	178	183	187	186	183	185
Oxygen Content %	8 3	8 1	8 0	7 6	7 4	7 3	7.0	6.7
Rel Ig. Temp , ° C..	182	180	183	192	188	185	192	195
Oxygen Content, %. ...	6 6	6 4	5 6	5 4	5 1	4 9	4.7	3.9
Rel. Ig. Temp , ° C.....	206	200	210	200	217	195	220	200

Ray W. Arms heated samples in a small furnace in communication with air, but shielded from currents, the coal temperature being taken by a thermocouple, and the point where the coal assumed a uniform glow being taken as the ignition temperature. The results were found to check well, and are shown below.

Coal from	Glow Points ° C.	° F.	Average ° C.	° F.	Difference in ° from average ° C.
Herrin, Williamson County, Ill (Bit)	433	811	440	824	—7
	451	844	...	...	11
	437	819	...	...	—3
Georgetown, Vermilion County, Ill "	453	847	456	852	—3
	453	847	.	...	—3
	466	871	...	...	10
	451	844	..	..	—5
Bennett Station, Vermilion County, Ill "	498	928	496	925	2
	494	921	...	...	—2
Old Ben No. 8, Johnson City, Ill. "	526	979	521	970	5
	525	977	..	...	4
	512	954	...	..	—9
Manitoba, Canada (Lignite).	535	995	526	978	9
	522	972	...	...	—4
	520	968	...	...	—6
Castle Gate, Utah (Semi-bit.)............	535	995	528	982	7
	524	975	...	...	—4
	525	977	...	...	—3
Lovington, Moultrie County, Ill. (Bit.)....	526	979	530	986	—4
	534	993	...	...	4
Lincoln, Logan County, Ill. ' "	559	1038	558	1036	1
	557	1035	...	...	—1
Anthracite, Pennsylvania	598	1108	600	1112	—2
	598	1108	...	...	—2
	605	1121	...	...	5
Coke	607	1125	606	1123	1
	607	1125	...	...	1
	605	1121	...	...	—1

CIRCULAR COAL PILING

960 Tons in Central Cone, 5100 Tons in Outer Ring

Unloading Car, Conveyor Under Car

Loading Car from Storage Pile

STORING AND RECLAIMING BY PORTABLE CONVEYOR

Both Towers Fixed

One Tower Movable

Both Towers Movable

CABLEWAY COAL SYSTEM

The glow point was found to be independent of ash, moisture, size of particles, slight variations from the normal air supply, or rate of heating, but is probably affected by oxygen content, and perhaps by other agencies made active by weathering. While it represents the behavior of a semi-coked residue from which a large portion of the volatile matter has been driven off, it is lower than the ignition temperature of the evolved gases. There is no indication at present that the glow point bears any direct relation to fire while in storage.

Storage Methods.— The following precautions are suggested for coal storage, although some may prove impractical and expensive under certain conditions:

1. Do not pile over 12 feet, nor so that any point in the interior will be over 10 feet from an air-cooled surface.

2. If possible, store only screened nut coal.

3. Keep out the dust as much as possible; reduce the handling to a minimum.

4. Pile so that the lumps and the fine are distributed as evenly as possible, by adding successive layers to a flat-topped pile. If the coal is deposited at one point, a conical pile is produced, in which the lumps will roll down the outside and the fines will collect in the center.

5. Re-handle and screen after two months.

6. Do not store near external sources of heat, even though the heat transmitted be moderate.

7. Allow six weeks' seasoning after mining and before storing.

8. Avoid alternate wetting and drying.

9. Avoid air transmission to the pile through interstices around foreign objects, brickwork, etc., or through porous bottoms, such as coarse cinders.

10. Do not ventilate with pipes, which may do more harm than good.

11. Draw fuel from any spot where the interior temperature seems unduly high, or if necessary, overhaul the pile at that point and flood it.

The *University of Illinois* states that land for coal storage should be well drained, but with no open drains directly under the pile, which might produce air currents through it. The land should be cleared of vegetation and leveled, so that no dirt will be taken up when it is reclaimed, and space should be available for relocation, if heating occurs. Coal should not be piled around hot pipes, against boilers or chimneys, nor where it is exposed to hot air from sewers. Small piles are preferred; the *U. S. Railroad Administration* suggested piling coal for railroad storage not over 12 to 15 ft. in height under a track, and 20 ft. when handled by a locomotive crane. *The Home Insurance Co.* advises against piling more than 12 ft. or 1500 tons per pile, and suggests trimming so that no point is more than 10 ft. from an air-cooled surface.

A fire in the coal pile cannot be put out by drenching the pile. A crust forms over the fire, preventing the water from reaching it. The coal must be removed from around the burning part, and spread out. Water can then effectively be used on the burning part. In practice, coal stored two months, if re-handled and cooled, seldom again heats spontaneously.

The *University of Illinois* states that if the coal temperature reaches 140° F. the pile should be carefully watched, and that if it rises rapidly to 150 or 160° F., the coal should be promptly moved and cooled off or used. If the temperature rise is slow, a higher temperature can be per-
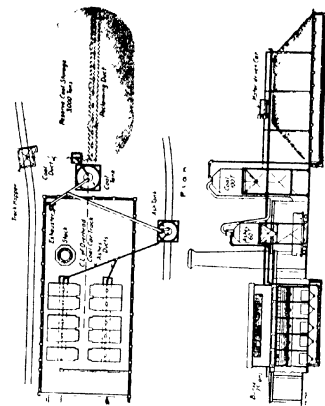
SUCTION CONVEYOR PLANT

Coal is taken from a track hopper by suction to a 100-ton coal tank from which it is delivered by motor-driven cars to the bunkers above the boilers. Reserve storage of 3000 tons provided at one end of the plant by continuing the track and delivering coal to a storage pile instead of to the bunkers. Coal from the storage pile is reclaimed by permitting it to run into an underground reclaiming duct from which it is sucked into the 100-ton coal tank. Bituminous screenings used.

—*Ill. Eng. Exp. Sta.*
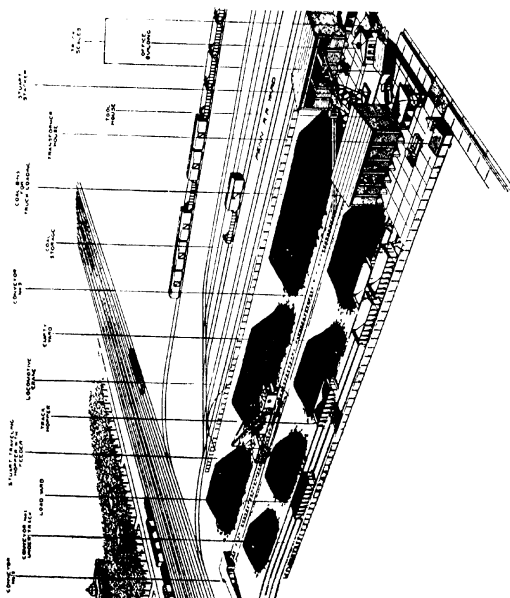
GOVERNMENT STORAGE PLANT, WASHINGTON, D. C.

mitted. Smoking is said to begin at 180° F.; steaming, however, is not especially dangerous. The presence of inflammable waste, tar, etc., in coal is a source of danger, as is air leakage through cracks in the base boards.

H. E. Birch and H. V. Coes call attention to the effect of piling coal by dropping it from a single point or from a source moving in a straight line, which causes the larger lumps to roll down the sloping sides, so that the pile is segregated and consists of lumps at the base and fines above, as in Fig. 1. Air thus enters the base and supports oxidation while the blanket of fines prevents the escape of the heat, fostering spontaneous combustion If the coal is piled in horizontal layers, as shown in Fig. 2, the interstices are filled with fines, so that air supply is restricted. A similar effect is secured by screening and piling each size separately, although this is more expensive than the horizontal-layer method. With the latter, the critical point (where air supply is sufficient to feed oxygen but insufficient to carry off the heat) is near the surface, but is subject to hourly change of position, which is a factor in elimination of spontaneous combustion C. G. Spencer says, however, that most Illinois and other Mid-West coal slacks rapidly in the air, and that lumps exposed to the atmosphere for a few days soon become fine and hence there is no advantage in layer storage for this type of coal.
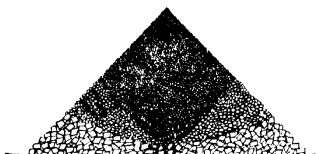
FIG. 1. CONICAL COAL PILE SHOW- ING SEGREGATION BY SIZE.
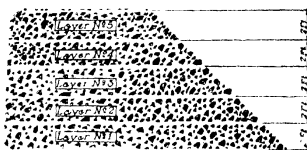
FIG 2 HORIZONTAL-LAYER* PILE, LUMPS UNIFORMLY DISTRIB- UTED

—A S.M E.

O. P Hood calls attention to the influence of amount of exposed surface on the rate of heating. A solid ton of bituminous coal would have a surface of 47 sq. ft, which becomes 1000 sq. ft in the case of 3-in. lump, 2000 sq. ft. for 1¼-in. nut, and 15,000 sq. ft. for the 1/10-in. size. The rate of heating rises with the amount of surface and with freshness of the breaking up, and falls with time Coal which is already broken and can be handled without appreciable breakage is therefore safe, and also the longer a pile stands without noticeable heating the greater is its probable freedom from ignition. However, the rate of surface oxidation doubles with every 10° rise in temperature. Coal stored on a hot day is therefore particularly subject to spontaneous combustion, and if the ventilation in any coal pile is insufficient the increased oxidation due to temperature offsets the drop due to lapse of time. Cases of actual combustion are surprisingly rare, considering the number of storage operations effected each year.

*Level of storage pile raised 2 ft. at a time by lowering the clamshell to a point just above the surface of the pile before discharging contents.

H. M. Ward describes a method by which the temperature throughout a pile of coal in storage can be systematically checked. By inserting ⅜-in. rods, the general location and depth of any hot spots can be determined by passing the hand along the rod, and the hot spots can further be investigated by lowering a thermometer into a pipe, and noting whether there is a steady increase of temperature. For complete protection in very hot weather, he recommends charting the pile into ten-foot squares, and inserting 1-in. pipes, with ends closed. Ten pieces of sash chain long enough to reach to the bottom are prepared, these are inserted one by one, and by the time the last is inserted, the first chain can be removed and its temperatures judged and recorded as cool, warm or hot. A plot should be marked up once a week or oftener if conditions warrant. For reducing temperature he recommends flooding through a section of perforated 1½-in. pipe thrust into the warm coal. He states that he has found the use of water applied through a row of perforated vertical pipes extending from top to bottom of pile advantageous for isolating and for checking the fire at any points which have actually ignited, as well as those which are dangerously hot, but calls attention to the fact that unless the quantity of water supplied is relatively large, it will reach such a high temperature itself as to endanger other parts of the pile to which it may flow.

Factory Mutual Record describes a method of packing and rolling coal which had formerly given trouble from fires. It is dropped from a bucket crane in layers about 3 ft. deep, packed down by a caterpillar tractor hauling an ordinary road drag, and tamped with a mallet around posts or other projections extending up through the pile. Layers are thus added to a depth of 15 to 30 ft., tightly packed with the air excluded and with the surface so hard that an automobile can be driven on it. The cost of leveling and rolling is about six cents per ton, increase in capacity about 30%, and the piles have been free from fires.
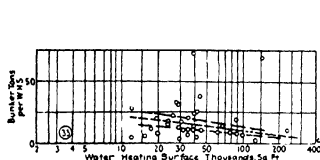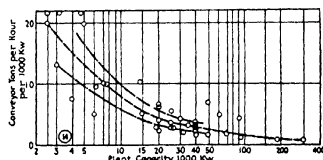
BUNKER CAPACITY   CONVEYOR CAPACITY

—*Power.*

John G. Fairchild gives the above charts for bunker and conveyor capacity in a number of modern plants.

Analyses by the *Bureau of Mines* showed the following losses in heat value in coal *in transit*. The losses were due to the oxidation of the new surface of the coal after mining.

Semi-bituminous New River and Pocahontas........0.1%
Bituminous Appalachian 0.3%
Bituminous from Illinois, Indiana and Missouri....0.8%
Sub-bituminous and lignite........................1.3%

While coal has a **specific gravity** between 1 and 2, and a solid cubic foot would weigh over 80 pounds, the weights of broken coal as mined and shipped range from 44 to 54 pounds per cubic foot, and in some cases, with anthracite, up to 58 pounds. The work of the *Bureau of Mines* indicates that in general coals with high fixed carbon, low ash or low moisture content, are the heavier; although no fixed relation has been discovered. Tests show that the weight of coal that can be contained in a unit volume can be increased 4 to 8% by shaking in the laboratory, while coal that has been subject to repeated shaking on a long haul, or to storage in large piles, will sustain 10 to 15% increase in weight per cubic foot. Coal of mixed sizes is naturally more compact, while wetting may temporarily increase the weight from 3 to 8%

COAL MEASUREMENT

The method to be used for measuring coal in the boiler plant depends upon the method of handling. Coal is transported either continuously by belts, chutes or chain bucket conveyors, or intermittently by grab buckets, tipping buckets or hoppers carried on cranes. In a few plants coal is transported directly from cars or the holds of vessels to the stoker hoppers. More frequently one or two places of storage intervene in the form of stock piles or bins, a common form being an overhead bunker in the boiler room. Coal is transported to the bunker by grab buckets operated by cranes or skip hoists, taking either from the coal car, vessel or pit into which coal cars are dumped, or by continuous belts or conveyors. With most kinds of coal and most types of stokers a crusher is interposed somewhere in this path. The weighing may be done in this part of the process, either by means of track scales weighing loaded coal cars, or by continuous weighing machines where belt or chain bucket conveyors are used. This gives little idea of the coal consumption unless the bunker is periodically leveled to lines, and even then it gives no record as to short periods or individual boilers.

Coal should be weighed on receipt, as a check on deliveries, and the total daily consumption should be recorded, as a gage of stock, while records for individual boilers or groups will serve as either a continuous or periodic check on coal quality and boiler performance. *The Coal Trade Journal* says that track and wagon scales, weighing hoppers, conveyor weighers and coal meters are used for checking receipts. The same devices, and also movable weighing hoppers and traveling larries, can be used for total consumption. For the individual records, automatic scales or coal meters are used, although movable hoppers can be used if care is taken to keep records properly separated. Small flush platform scales are of course available where coal is wheeled in by hand.

Platform scales, used for wagons, trucks or cars, can be equipped with automatic devices for printing weights on a tape. With track scales, a section of the railway track or the overhead monorail is supported on the scale beam and the car or larry or trolley passing along it is halted and weighed.

The traveling weigh hopper is used to take coal from overhead bins located either in or near the boiler room, and deliver it to the stokers. It is suspended from tracks, and is operated by hand or motor, according to size. The weighing can be done by hand-operated scales, preferably equipped to record the weights, or by automatic scales. If the automatic scale is interposed between the upper hopper and a receiving hopper delivering to the stokers, a record is obtained of total consumption, and the coal is distributed to the individual stokers as desired. To secure individual records, the automatic scale is placed below and records the number of loads actually delivered to the stoker hopper.

With large boilers, a 100-lb. automatic scale can be placed in front of each boiler, requiring very little space and practically no attention except when filling the upper hopper.
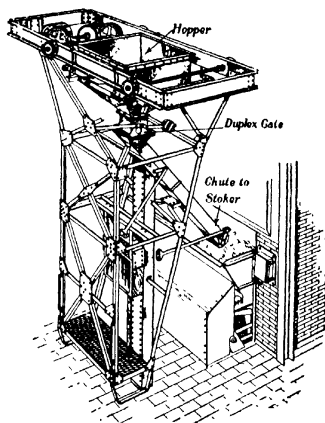
TRAVELING WEIGH HOPPER
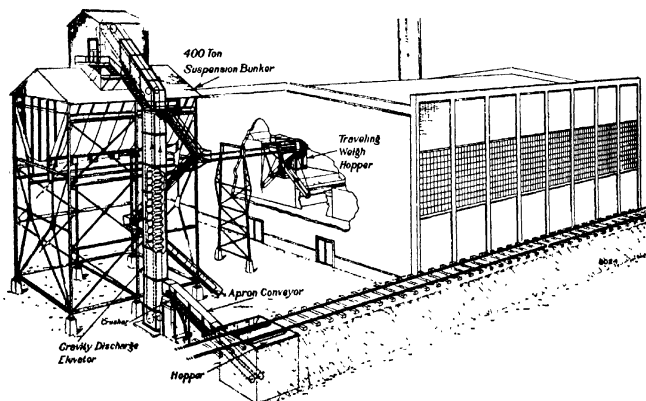
COAL HANDLING AND WEIGHING SYSTEM

Automatic scales have hoppers so arranged that the supply is shut off as soon as the hopper fills to a given weight, say 500 pounds, after which the hopper discharges and refills, each load being recorded automatically. These devices can be placed under a large receiving hopper into which the coal is discharged as delivered, or at some transfer point in the conveyor system.

Conveyor weighers are arranged to weigh the coal while in motion on belt or bucket conveyors, of which a short section is supported by a floating platform, balanced in one type by an iron weight floating in mercury, the position of which depends on the momentary load. This affects the angle of contact of a revolving disc with a belt having a motion proportional to that of the conveyor belt, so that a revolution counter attached to the disc serves to integrate the amount of coal passed

The *Havard* coal meter consists of a screw inserted in a gravity spout, and is calibrated empirically for different grades and sizes of coal. Screw conveyor meters are also used, or control valves in pairs in the chutes.

WOOD AND OTHER SOLID FUELS

Hogged Fuel.— This term is properly applied to wood slabs, edgings, trimmings, etc., which have been put through a "hog" to reduce them to a uniform small size, but is also used for shavings from planing mills, sawdust from saw-kerfs, bits of bark, chips and other small recovered products from the manufacture of lumber. *H. W. Beecher* mentions four types of hog machines. One differs but slightly from the chipper used to prepare wood in a paper mill for the digester in the production of sulphite pulp, and consists of a steel disk to which are attached knives. A second type consists of two concentric cones bearing knives which revolve in a conical-shaped housing. A third hog is one in which a cylinder fitted with a row of knives revolves in a cylindrical housing. The fourth type is known as a "hammer hog," in which the wood is broken up by the impact of a series of hammers operating against the edges of anvils. The knives soon become dulled by tramp iron, and must be renewed to furnish chipped instead of a shredded product. When fuel has to be "rehogged," it is well to use two types in series. Sawmills in the Northwest usually have a salable surplus of $\frac{1}{3}$ to 1 unit (average $\frac{1}{2}$) per 1000 ft. of logs handled, above their own requirements for power, a "unit" being 200 cu. ft. of hog fuel. In 1925 it could be sold, where a market was available, to net the mill owner from 50 cents to $1 00 per 1000 ft. of lumber produced, while if used at the mill for large-scale generation of power, 600 to 750 kw. hr. could be produced per unit.

Beecher gives the following table for available *BTU* in hog fuel with varying boiler efficiency and varying percentage of moisture. In this table the available heat is defined as the heat left in the fuel for evaporative purposes after deducting the heat necessary to heat, evaporate, and superheat the moisture in the fuel to an assumed stack temperature of 550°, and is computed on the basis of 8500 *BTU* per lb. of dry fuel. While tests show that the *BTU* per lb. of dry fuel in most soft woods will run closer to 9000, the low value is assumed to account for variation in stack temperature, resin content, incoming-fuel temperature, etc., and the available heat as calculated and given in the table is still slightly conservative. The boiler efficiency used in this table is not based on the ratio between the

total heat put into the furnace and the total heat represented in the steam generated in the boiler, but, for convenience in calculation, has been based on the heat available for production of steam.

AVAILABLE HEAT IN HOG FUEL

% Moisture By Wt	Total Heat Available H, BTU per Lb.	Boiler Efficiency, %			
		40	50	60	70
10	7523	3009	3760	4514	5266
20	6546	2618	3273	3928	4582
30	5569	2228	2784	3341	3898
40	4593	1837	2297	2756	3215
50	3615	1446	1808	2170	2531
60	2638	1055	1319	1583	1847
70	1661	664	831	997	1163

Formula. $H = 8500 \ (1 - P) - P(970 \ 4 + 150 + 150)$.
$P =$ Fraction of moisture

The following table of fuel required for a boiler HP hr. output is based on an assumed specific gravity of 0 40 for solid dry Douglas fir or hemlock, and a ratio of 2½ cu. ft. hog fuel per cu. ft. solid wood. The latter ratio actually varies from 1 8 to 3.8, depending on percentage of fines, saw-kerf and shavings, on condition of hog knives, on the time the fuel has stood in containers and the jarring or packing to which it has been subjected.

CUBIC FEET OF HOG FUEL PER BOILER-HP HOUR AT VARIOUS EFFICIENCIES AND MOISTURE CONTENTS IN FUEL

% Moisture By Wt.	Boiler Efficiency, %				
	40	50	60	70	100
10	0.900	0.720	0.600	0.513	0.360
20	0.920	0.735	0.615	0 527	0.369
30	0.947	0.758	0.632	0.540	0.378
40	0.985	0.787	0.655	0 563	0.394
50	1.042	0.833	0.695	0 594	0.416
60	1.145	0 913	0.763	0.653	0.457
70	1.362	1.090	0.910	0.778	0.545

In general resinous woods burn best, but little account is usually taken of resin content, or of whether the refuse is of fir, hemlock, spruce, cedar or alder. The unit of 200 cu. ft. averages 4000 lb., containing 42% moisture by weight, but because of variation of voids, weight of dry wood and moisture content, the weight may vary from 2500 to 5000 lb. Boiler results vary from 8000 to 13,500 lb. equivalent evaporation per unit, and, for the few tests in which moisture has been determined, from 3 to 6 lb. per lb. of *dry* fuel. Electrical generation has varied from 200 to 750 kw. hr. per unit, but with economizers and high pressure and superheat it should be possible to obtain over 1000 kw. hr. The ultimate analysis of an average sample of dry wood is approximately as follows:

	%
Carbon	50.0
Hydrogen	6.0
Oxygen	43.5
Nitrogen (less than).....	1.0
Ash	balance

A proximate analysis on a dry-wood basis would show in the neighborhood of

	%
Volatile	81.5
Fixed Carbon	17.5
Ash	1.0

Hog fuel stored outdoors shrinks 10 to 35% from settling after rains, and also loses about the same amount in heating value from escaping volatiles, little further depreciation occurring after the first six months.

H. S. Bastian gives the following as a typical analysis of fresh "hogged fuel" from operations on Douglas fir:

FIXED CARBON AND VOLATILE IN HOGGED FUEL —*Elec. World*

Moisture	49.9%
Volatile combustible	39 7
Fixed carbon	11.7
Ash	0.7

BTU per lb dry	8970
BTU available as fired	4050
Lb. per "unit" (pile of 200 cu. ft)	3900

The figure shows the general relation between analyses of hogged fuel and the heat content. It is believed that a portion of the CO_2 in flue gases from such fuel is sometimes the result of dissociation, rather than heat-producing combustion. It is important that no CO and but little free oxygen be present, as well as high CO_2.

ANALYSIS AND HEAT VALUE OF VARIOUS WOODS —*Power Plant Engg.*

	% Carbon	% Hydrogen	% Oxygen	% Nitrogen	% Ash	BTU per lb. dry
Ash ..	49.18	6.27	43.91	0.07	0.57	8480
Beech..	49.06	6.11	44.17	0.09	0.57	8591
Elm ..	48.89	6.20	44.25	0.16	0.50	8510
Oak ..	50.16	6.02	43.36	0 09	0.37	8316
Fir ...	50.36	5 92	43.39	0.05	0.28	9063
Pine ..	50.31	6.20	43.08	0.04	0.37	9153

CHARACTERISTICS OF SAWMILL REFUSE FUELS—*Darrah Corbet*

Name of Wood	Location	% Moisture	Fuel Characteristics
Birch	Michigan	40 to 45	Fair burning
Cedar	W. Wash., Ore., and Brit. Col.	45 to 55	Fair
Cedar	Central California	40 to 50	Fair
Cypress	Florida, Texas, Mississippi	35 to 54	Fair
Fir	Wash., Ore., British Columbia	35 to 45	Good
Fir	Central California	35 to 50	Poor
Hemlock	Wash., Ore., British Columbia	40 to 50	Poor
Hemlock	Michigan	45 to 55	Poor burning

Maple	Michigan	40 to 55	Fair
Pine-Cork	Eastern Washington, Idaho	35 to 45	Fair
Pine Long leaf	Florida and Gulf Coast	40 to 50	Fair burning
Pine Short leaf	Florida and Gulf Coast	40 to 50	Fair burning
Pine Short leaf	Florida and Gulf Coast	20 to 40	Fair burning
Pine White	Mexico	45 to 55	Fair burning
Pine White	California	30 to 45	Fair burning
Pine Sugar	California	40 to 65	Poor
Pine Yellow	Central California	40 to 45	Fair
Redwood	California	45 to 50	Poor

COMPARATIVE HEATING VALUES, AIR DRIED

L. P. Breckenridge

	BTU per lb.	Weight, Lb per cord	Lb. of 13500-BTU coal equivalent 1 cord of wood
Straw	5100		
Lignite	5200–7500		
Chestnut, elm	5400	2350	940
Beech	5400	3250	1300
White oak	5400	3850	1540
Hickory	5400	4500	1800
Cherry	5420	3140	1260
Ash	5450	3520	1420
Hard maple, walnut, red oak	5460	3310	1340
Live oak	5460	3850	1560
Birch	5580	2880	1190
Tanbark	6100		
Hemlock	6410	1220	580
Yellow pine, poplar	6660	2130	1050
White pine, spruce, willow	6830	1920	970
Peat, air-dried	7500		
Corn	7200–8200		
Bagasse	8300		
Bituminous coal	9500–14500		
Anthracite	11500–14000		
Crude oil	17500–21000		
Kerosene, 0.863 sp. gr.	18700		
Gasoline, 0.710 sp. gr.	18500		
Hydrogen	62000		

Bagasse, the refuse from grinding sugar cane, represents about 20% of the weight of cane handled, and has good heating value. Louisiana bagasse averages 40% fiber, 7% sucrose and 53% moisture. The heating value of dry bagasse is 8300 BTU per lb., and that of the raw product is represented by the formula 83 (100-M) — 12.5M, where $M =$ the % moisture, and the deduction covers the heat required to evaporate and superheat the moisture.

David M. Myers states that the ultimate analysis of **tanbark** is approximately 52% C, 6% H, 41% O, ash 1.4%, which should, by DuLong's formula, represent 8084 BTU per lb. high heating value, while bomb calorimeter tests show an average of 9500 BTU, which would suggest that some of the oxygen assumed to be united with hydrogen is really combined with carbon. As fired, it contains 65% moisture, the available

heat per lb. as fired, after subtracting moisture loss, being about 2500 *BTU*. The moisture content can be reduced to 58% by pressing, representing about 8% heat saving, and decreasing the required grate surface by one-third, which may justify the pressing in some cases.

OIL FUELS

Petroleum in its crude form is a mixture of a number of hydrocarbons, which can be separated by fractional distillation. While the raw product is sometimes used as fuel, the usual practice is to "top off" the more volatile gasoline, naphtha, kerosene and gas oil, not only conserving these valuable products, but reducing the fire hazard of the residual oil. Oils of the paraffin or saturated-base type, from the Appalachian range and Middle West, are dark brown in color, with a greenish tinge. The residuum from these usually contains such valuable lubricating stock as to preclude its use for fuel. The asphaltic base oils, from Texas, California and Mexico, run from reddish brown to black, and quantities of residuum from these are available, because of the large market for the volatile distilled from them. The olefine-group oils, from Russia, are also suitable, and Panuco crude oil from Mexico retains so little volatile after handling and transportation as to be available without refining.

Fuel oils consist almost entirely of carbon and hydrogen, and their heating value depends on the amounts of these constituents by ultimate analysis, being little influenced by the composition or volatility of the compounds in which they exist. The principal factors determining the availability of a fuel oil are its price on a heat unit basis, its freedom from grit, acid, fibre and sulphur, and the possession of a flash point over 150° F. and a viscosity that will enable it to be pumped at 60° F.

Oil shale does not contain any commercially valuable oil as such, but it does contain, in the form of animal and vegetable remains, the chemical constituents which, when subject to destructive distillation, yield oil and gas. Kentucky shale contains 75 to 85% ash, but according to *V. C. Anderson* an average of half a barrel of oil (21 gal.) can be recovered per ton. The Scott retort is 20 ft. high, with ten fire-clay sections set one above the other, tapering, fired by external burners so that the descending shale is subject to a gradual increase of temperature from 400° to 2000° F., and non-condensable gases recovered in connection with the oil are more than sufficient to operate the retorts.

Oil is sold by volume, on the basis of 42-gallon barrels, and on the average of 8 lb. per gallon, a barrel represents about 336 lb., whereas in the Southwest the commonly-accepted weight is 310 lb. per barrel, based on 7.4 lb. per gallon. In English ports the long ton of 2240 lb, subdivided into the hundredweight (112 lb.) and the quarter (28 lb.) is used. Specific gravity of commercial fuel oils is ascertained by a Baumé hydrometer, which is a standard, weighted, glass bulb with a graduated rod indicating the depth to which it sinks in the fluid under test. This instrument is depressed slightly below equilibrium point, and allowed to come to rest. The reading is taken at the principal surface of the liquid, which is judged by placing the eye slightly below it and raising the eye until the surface appears as a straight line. If the oil is opaque, reading is taken at the top of the meniscus, and a correction made. Standard Baumé graduations begin at 10°, for a specific gravity of
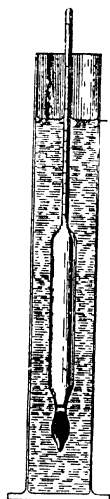
BAUMÉ HYDROMETER
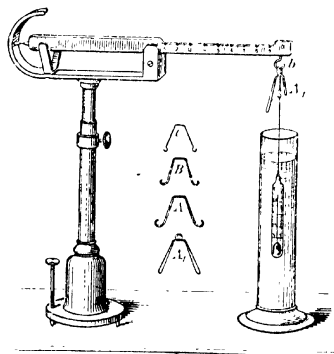
WESTPHAL SPECIFIC GRAVITY
BALANCE

1 (same as pure water), and increase as the specific gravity decreases, according to the relations

$$\text{Specific gravity} = \frac{140}{130 + \text{Baumé}}, \quad \text{Baumé} = \frac{140}{\text{sp. gr.}} - 130$$

The Tagliabue hydrometer, used by the Petroleum Association, is calibrated by a slightly different rule.

$$\text{Specific gravity} = \frac{141.5}{131.5 + \text{Baumé}}$$

(These apply only to liquids, such as oil, which are *lighter* than water.) Precise determinations of specific gravity are made by the *Westphal* balance, which consists of a bulb which is supported in the liquid by an accurate balance and system of riders.

RELATION OF BAUMÉ READINGS TO DENSITY AND VOLUME
—*Bureau of Mines*

° Baumé	Spec Gr 60°/60° F.	Lb per gal.	Gal. per lb.
10 0	1.0000	8.328	0.1201
15.0	0.9655	8.041	.1244
20.0	.9333	7.772	.1287
25.0	.9032	7.522	.1330
30.0	.8750	7.286	.1373
35.0	.8485	7.065	.1415
40 0	.8235	6.857	.1459

Where oil is bought on the basis of its volume at 60° F., the volume delivered can be adjusted by using the expansion coefficient. For California oils this is taken as 0.0004 per ° F.

Viscosity of an oil is the measure of its internal friction, or resistance to flow. It varies with temperature. Degrees Engler is the ratio of the time for a sample to flow through a standard orifice, compared with water. Results from the Redwood, Saybolt and Tagliabue viscosimeters are expressed in seconds for a given flow. High viscosity is objectionable as interfering with pumping and with atomization.

Moisture may collect at the bottom of containers or may exist as an emulsion. The amount of the latter can be ascertained by distillation, by centrifugal separation, or by shaking with gasoline and allowing to settle.

Heating values are determined experimentally by calorimeters. Weighed samples are ignited in the sealed bomb b, in oxygen under 25 atmospheres, or sodium peroxide, and results are calculated from the temperature increment of the water surrounding b.
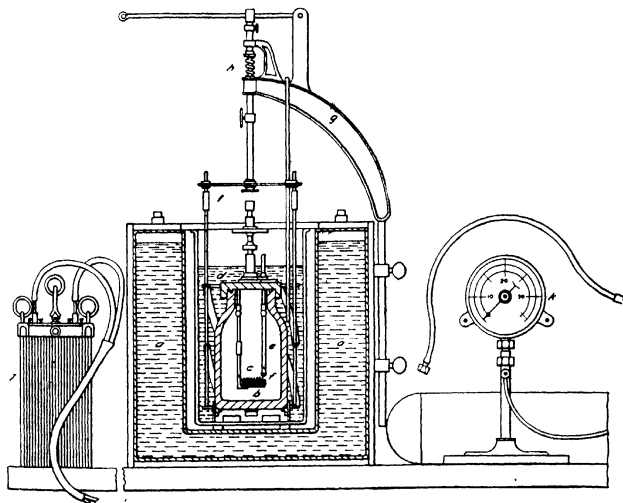
MAHLER FUEL OIL CALORIMETER.—*Bureau of Mines*

a, water vessel in which bomb is placed; b, steel bomb; c, platinum capsule to hold fuel; d, lead-lined clamp gripping bomb; e, platinum rod, connected to insulated piece passing to exterior but electrically insulated from bomb; f, short coil of wire. platinum or iron. wound around terminal of rods and in contact with fuel; g, arm supporting stirrer; h, drive thread for stirrer; i, lever for operating stirrer; j, battery for firing; k, manometer connected to oxygen supply; l, stirrer.

TEMPERATURE-VISCOSITY DIAGRAM FOR FUEL OILS
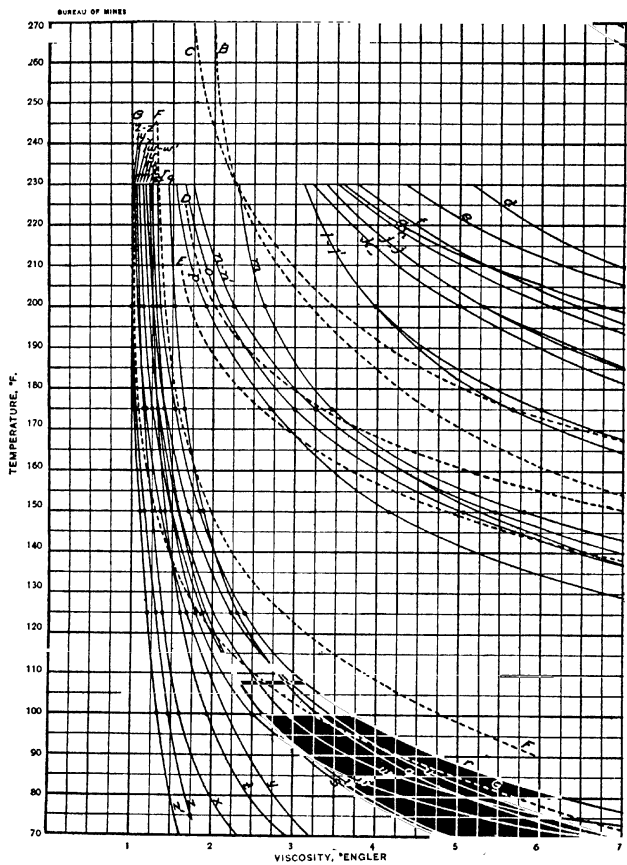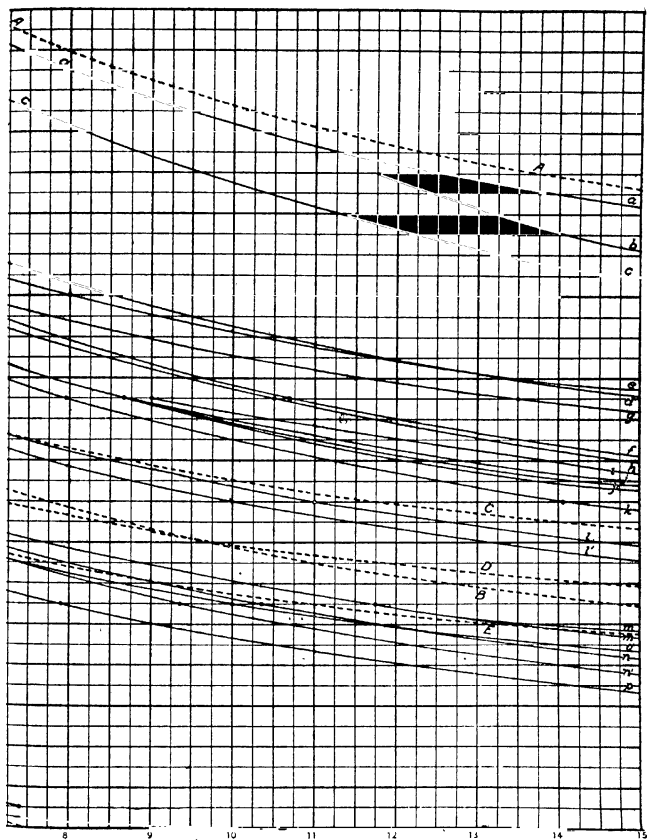
TEMPERATURE-VISCOSITY DIAGRAM FOR FUEL OILS—*Contd.*

Test data indicated by black dots. See page 118 for names of oils tested.

DATA FOR TEMPERATURE-VISCOSITY DIAGRAM ON PAGE 117

Solid Curves by Lieut. Commander J. J. Hyland, U. S. Navy

Curve No	Type of oil	Sp. gr.	° B.	Flash point, ° F.
a	Mexican residue	1.000	10 0	374
b	"Toltec fuel oil," Inter-Ocean Oil Co , N. Y.	.988	11 7	220
c	"Toltec or Panuco oil " Inter-Ocean Oil Co	986	12 0	124
d	"No 102 " Union Oil Co Bakersfield, Cal .	.980	12 9	280
e	"No 18," Union Oil Co Bakersfield, Cal	.980	12 9	285
f	"Standard" Mexican crude (lot 2)	.964	13 4	202
g	"No 25," Union Oil Co , Bakersfield, Cal	978	13 2	262
h	Mexican crude, Texas Co...	.952	17 3	126
i	Sample No 3, Anglo-Mex Pet Products Co	.952	17.3	164
j	"Gaviota Refinery," Associated Oil Co , Cal.	.953	17.1	230
j'	Mexican oil, Atlantic torpedo flotilla, March, 1914	.947	18 1	182
k	Standard Mexican crude (lot 1)	954	17 0	145
l	Mexican oil, U. S. S. *Arethusa* ...	.950	17 6	182
l'	"Nos 1, 2, 3," Anglo-Mexican Pet Prod Co	.955	16 8	188
m	Producers Crude No. 1 fuel oil, Union Oil Co., California	959	16 1	174
n	"Coalinga Field," Associated Oil Co , Monterey, Cal.	.957	16 5	186
n'	"Avon Refinery," Associated Oil Co , Avon, California	.953	17 1	168
o	Richmond, California	.953	17 1	238
p	Sun Co , Louisiana	936	19 8	275
q	"Standard," Illinois	.893	27.3	146
r	Gulf Refining Co., Navy standard oil, U. S. S *Perkins*	.892	27 5	180
s	"Standard," Indiana	880	29 6	144
t	"Standard Star," California	912	23 9	180
u	"Standard," Illinois (lot 4) .	893	27 3	146
v	"Standard " Indiana (lot 4).	.880	29 6	144
w	Gulf Refining Co , Navy contract	882	29 3	170
w'	"Standard " Lima, Ohio, crude	876	30 4	149
y	"Star," California	.912	23 9	180
z	Gulf Refining Co , Navy standard oil, U. S. S *Roe*	.885	28 7	182
z'	Standard Mexican gas oil	.856	34 2	151

Dotted Curves, by E. H. Peabody

A	Panuca crude, Inter-Ocean Oil Co .	975	13.7	140
B	Mexican petroleum, Texas Co	938	19 5	234
C	Associated Oil Co., California	971	14 2	257
D	Bakersfield, Cal., pipe line to Port Costa	.970	14.4	260
E	California Standard Oil Co., steamer *Santa Barbara*	962	15 7	282
F	Beaumont, Tex , Gulf Refining Co	907	24 8	222
G	Navy Standard oil, Texas Co	911 to .900	24 to 26	195 to 220

From an ultimate analysis, the heating value can be determined by DuLong's formula (see page 58), or by the following empirical formula by *W. Inchley:*

$$BTU \text{ per lb.} = 13,500 \ C + 60,890 \ H,$$

where C and H are proportions by weight of carbon and hydrogen. Another formula, due to *Sherman* and *Kropff,* is based on specific gravity, and has given results which correspond to calorimeter reports even better than those from ultimate analyses:

$$BTU \text{ per lb.} = 18,650 + 40 \ (\text{Baumé} - 10)$$

$$= 13,050 + \frac{5600}{\text{sp. gr.}}$$

The determination of heating value by the calorimeter or from the ultimate analysis gives the theoretical or "high value." For the "low value" an arbitrary deduction of 8730 H is made from the high heating value per lb. of oil, where H is the fraction of hydrogen in the oil, on account of heat necessarily carried from the furnace in steam from the combustion of hydrogen. For the average fuel oil the deduction is approximately 1000 BTU per lb. (See also page 50)

The specific gravity of crude oils lies between 0.80 and 0.97 (45 to 14° Baumé), the flash point being between 140° and 300° F, and the composition by weight 84 to 88% carbon, and 11 to 14% hydrogen, with traces of sulphur, oxygen, nitrogen, phosphorus, arsenic and silt. The residuum oils are very similar in ultimate analysis, with a specific gravity about 0.90, and an average flash point of 250° F. The average heating value of commercial fuel oils is 18,500 BTU per lb.

ANALYSIS AND CALORIFIC VALUE OF OILS (C E Lucke)

	Density at 60° or 70°F		Ultimate Analysis				Heating Value BTU per lb.	
	Sp gr	° Bé	C	H_2	$O_2 + N_2$	S	High	Low
California fuel	.966	14.93	81.52	11.61	6.92	.55	18,926	17,903
Texas, Beaumont fuel	.926	21.25	83.26	12.41	3.83	50	19,654	18,570
California crude	.957	16.24	86.30	16.70		80	21,723	21,254
Texas, Beaumont crude	.924	21.56	84.60	10.90	2.87	1.63	18,977	18,025
Pennsylvania crude	.914	23.18	86.10	13.90		06	20,949	19,735
Kansas crude	.866	31.67	85.40	13.07			20,345	19,203
West Virginia crude	.841	36.47	84.30	14.10	1.6		20,809	19,578
Ohio crude	.829	38.89	85.00	13.80	.6	6	20,752	19,547
Mexico	.921	21.90	83.70	10.20		4.15	18,840	17,800
Russia	.938	19.30	86.60	12.30	1.10		20,138	18,990
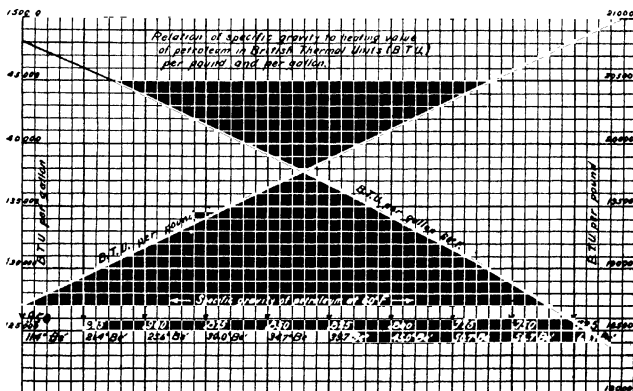
RELATION OF HEATING VALUE TO SPECIFIC GRAVITY OF FUEL OILS.—
Kansas City Testing Laboratory

The flash-point is the temperature at which the oil begins to give off appreciable quantities of inflammable vapors. It is determined by heating the oil and testing with a lighted taper or spark. Closed-cup testers include the New York State, the Abel and the Pensky-Martens, shown on page 123. Open-cut testers, as the Tagliabue and Cleveland, give a higher flash-point.

The flash-point standard of 150° F. (closed-cup tester), although somewhat arbitrarily fixed, has been accepted by the U. S. Navy, American Bureau of Shipping, British Admiralty, Lloyds, National Board of Fire Underwriters and National Fire Protection Association. *H. E. Newell* discusses the tendency to use in the untopped, or crude condition, low-grade asphaltum-base Mexican oils, such as Panuco River. This has a maximum volatile content of 3 to 5%, too low for profitable refining, but even with this small amount, vapor is given off at ordinary temperatures, causing a fire hazard from leakage and in filling and handling, and there is also danger of unburned oil finding its way into the combustion chamber, vaporizing there and igniting so rapidly, on starting up, as to blow out the front of a boiler setting. Untopped oil contains free mineral and organic matter, causing carbonization troubles and a tendency for the highly-heated foreign matter to sink to the bottom and start local heating which finally results in boiling. Lloyds and the American Bureau of Shipping permit the use of untopped oil on ships specially fitted for such fuel. The danger from untopped oil increases with the volatile content, although under normal conditions the ordinary mid-continent crudes would of course be refined to recover the volatile. He states that 150° F. should be adhered to unless tests should demonstrate the safety of a lower figure, such as 100° F.

UNITED STATES GOVERNMENT SPECIFICATIONS FOR FUEL OIL

Mandatory for use after June 18, 1924, compiled by the Federal Specifications Board, and published by the Bureau of Mines.

Fuel Oil (Navy Standard). This specification covers the grade of oil used by the United States Government and its agencies where a high-grade fuel oil is required. This oil may be used in Diesel engines. Fuel oil shall be a hydrocarbon oil, free from grit, acid, and fibrous or other foreign matters likely to clog or injure the burners or valves. If required, it shall be strained by being drawn through filters of 16 meshes to the inch. The clearance through the strainer shall be at least twice the area of the suction pipe, and the strainers shall be in duplicate. The flash point shall not be lower than 150° F., method 110.21 (see page·121). In case of oils having viscosity greater than 30 sec. at 150° F. (8° Engler) the flash point shall not be below the temperature at which the oil has a viscosity of 30 sec. The viscosity shall not be greater than 100 sec. at 77° F., method 30.4. Sulphur shall not be over 1.5%, method 520.21. Water and sediment combined shall not amount to over 1%, method 300.3.

Bunker Fuel-Oil "A", used where a low-viscosity oil is required, may be used in Diesel engines. Same as Navy Standard, with omission of sulphur clause.

Bunker Fuel-Oil "B", used where a more viscous oil than bunker oil "A" can be used. This oil may be used in Diesel engines of a type

adapted to an oil of medium viscosity. Same as "*A*," except: The flash point shall be not lower than 150° F. The viscosity shall be not greater than 100 sec. at 122° F.

Bunker Fuel-Oil "C", used where a high viscosity oil is satisfactory. This oil may be used in Diesel engines of a type adapted to an oil of high viscosity. Same as "*B*," except: The viscosity shall not be greater than 300 sec. at 122° F. The sediment content shall not be more than 0.25%, and total water plus sediment shall not be more than 2%, methods 300.11 and 300.2. A deduction in quantity will be made for all water plus sediment in excess of 1%.

Flash-Point test by means of Pensky-Martens Closed Tester, method 110 21, A. S. T. M. method D93-22. The apparatus includes a brass cup *A*, 2 in. in diameter, with stirrer and propeller blades *B* driven by a flexible shaft *C*, a cast-iron bell-shaped air-bath *D* protecting the cup from the flame, thermometer *E*, and a flame-exposure device *F* with pilot light *G*. The air-bath may be heated by electric resistance wire evenly distributed over bottom and walls, instead of a flame. A revolving cover shutter simultaneously opens observation holes and a flame hole when the flame is depressed to the level of the top of the cup. The cup is cleaned and dried, with all trace of inflammable cleaning fluid removed, and filled with oil, and test flame adjusted to the shape of a bead $\frac{5}{32}$ in. in diameter. The oil is heated at rate of 9 to 11° F. per minute, while stirrer revolves at 1 to 2 rev. per sec. Up to 220° F. readings are taken on a low-range "P. M. and Tag" thermometer, which is the A. S. T. M. standard for use with the Pensky-Martens or the Tag closed tester, and is an 11-in. mercury thermometer, nitrogen filled, for $2\frac{1}{4}$ in. immersion, graduated every degree from 20° to 230° F. The flame is applied every 2°, beginning at least 30° F. below the anticipated flash point The device operating the shutter and test-flame burner is so manipulated that the flame is lowered in $\frac{1}{2}$ sec., left down 1 sec., and quickly raised, all with the stirrer stationary. The flash point is taken as the temperature read on the thermometer at the time of the flame application that causes a distinct flash in the interior of the cup, as distinguished from a bluish halo observed with the applications immediately preceding. A "P. M. High" thermometer is used for temperatures above 220° F., and the flame is inserted every 5° F. For each inch barometric pressure above 29.92 in., 1.6° F. is added to the flash point.

Viscosity test by means of Saybolt Furol Viscosimeter, method 30 4, A. S. T. M. method D88-23T. The apparatus consists of a metal tube *A*, 1.17 in. diameter by $3\frac{1}{2}$ in. long, with an overflow cup *B*, an outlet tube *D* about $\frac{1}{2}$ in. in diameter, and a constant-temperature bath (not shown) surrounding *A*, with special thermometers designed for total immersion, graduated to 0.2° F., for measuring the oil and the bath temperatures. The receiving flask has a capacity of 60 c.c., at 68° F. The tube is cleaned and then flushed with warm oil of the sample to be tested, and the cork stopper *C* inserted, forming an air cushion between the stopper and the outlet tube. The sample is heated to nearly the test temperature and poured into the tube until it overflows and ceases to overflow into the overflow cup, and slowly raised to the desired temperature by heat applied outside the bath, which can be filled with water for tests at 77° or 122° F. Both liquids are stirred, and when the temperatures become constant, a pipette is used to lower the oil level in the overflow cup below the top of the tube. The receiving
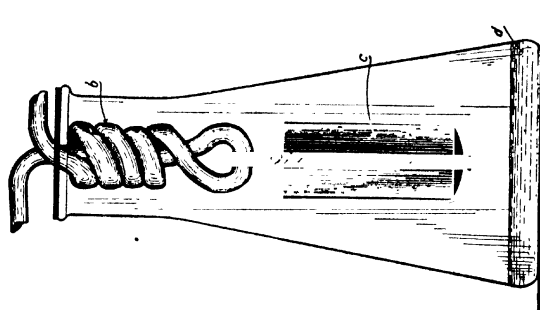
EXTRACTION APPARATUS FOR DETERMINATION OF SEDIMENT
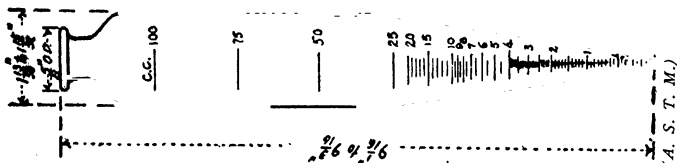
CENTRIFUGE TUBES (A. S. T. M.)
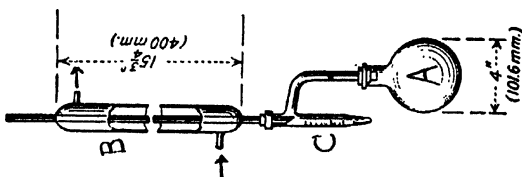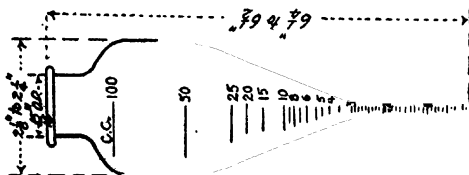
APPARATUS FOR DETERMINATION OF WATER
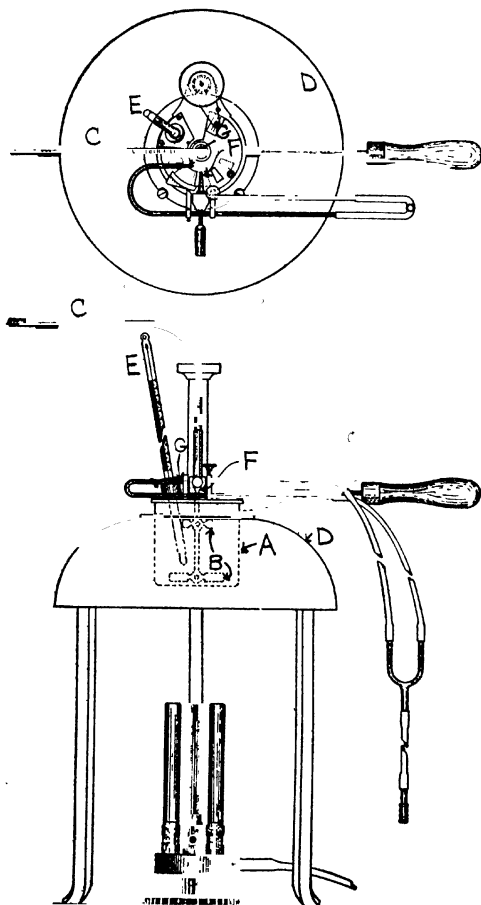
PENSKY-MARTENS CLOSED TESTER FOR
DETERMINING FLASH POINT
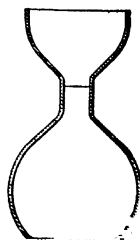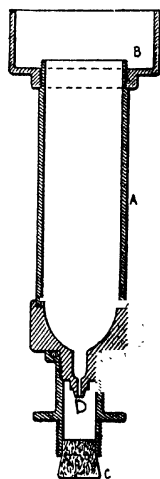
SAYBOLT
VISCOSIMETER
—A.S.T.M.

flask is placed so that the current running into it will strike the inside of the neck, to avoid foaming, and a stopwatch used to note the time intervening between the removal of the cork and contact of the bottom of the meniscus with the mark on the flask. The time for delivery of 60 c.c., in seconds, is the Saybolt Furol viscosity at the test temperature.

The sulphur test for fuel oil, method 520.21, A. S. T. M. method D129-22T, consists of electrically igniting a 0.6 to 0.8 gram sample of the oil in an atmosphere of compressed oxygen in a bomb, washing the bomb and treating the liquor with hydrochloric acid, bromine water and barium chloride The percentage of sulphur

$$= \frac{\text{grams of } BaSO_4 \text{ precipitated} \times 13.734}{\text{grams of oil used}}$$

Water and sediment determination by Centrifuge, method 300.3, A. S. T. M. method D96-21T. This requires two graduated glass centrifuge tubes, of either of the types shown in the figure, and means for whirling them safely at a speed of 1500 rpm with the tips of the tubes pointing outward and 16 in. apart, properly cushioned with water or rubber. With other sizes of whirlers, the speed should vary inversely as the square root of the diameter. 30 c.c. of 90% benzol is measured into each tube, with 50 c.c. of a thoroughly-representative sample of the oil to be tested, and the tubes are stoppered, shaken, and placed in a water or oil bath at 100° F for 10 min. They are then whirled in the centrifuge for 10 min., and the separated amount of water and sediment recorded. This is repeated till the amount agrees for three consecutive readings, which is then recorded as the percentage of water and sediment. Duplicate determinations should agree within 0.2 c.c., but will usually be less than the true value.

Water determination by distillation, method 300.11, A. S. T. M. method D95-23T. This requires a glass flask A, with an outlet tube ½ in. diameter, leading to a condenser B in which cooling water circulates in the jacket surrounding the tube, with a graduated leg or trap C in which the condensed water is collected. 100 c.c. of the oil is placed in the flask, with 100 c.c. of gasoline free from water, used in rinsing the measuring cylinder. The apparatus is connected, and the flask heated at such a rate that the condensed water falls into the trap at the rate of 2 to 5 drops per sec., until no water is visible except at the bottom of the trap, which should take less than an hour. The persistent ring of condensed water in the condenser tube is removed by increasing the rate of distillation for a few minutes, after which the collected water is measured at room temperature and the % water by volume calculated.

Sediment determination, method 300.2. A porous alundum thimble c, 1 in. diameter by 2¾ in. high, is filled with 10 grams of the oil, and suspended from condenser coils b. surrounded by the vapor from boiling 90% benzol in the bottom of the flask. Liquid benzol falls from the condenser into the thimble and gradually dissolves the oil and seeps away, leaving the sediment. When the dripping solvent from the thimble becomes colorless, the thimble is dried for 1 hr. at 105° C., and the increase in weight noted. This is repeated until no variation is found, upon which the increase is reported as sediment.

Sampling Fuel Oil.—The *Bureau of Mines* suggests the following procedure in taking samples for the commercial valuation of fuel oil:

The accuracy of the sampling, and in turn the value of the analysis, must necessarily depend on the integrity, alertness and ability of the person who does the sampling. No matter how honest the sampler may be, if he lacks alertness and sampling ability, he may easily make errors that will vitiate all subsequent work and render the results of tests and analyses utterly misleading. A sampler must be always on the alert for sand, water and foreign matter He should note any circumstances that appear suspicious, and should submit a critical report on them, together with samples of the questioned oil.

Immediately after the oil begins to flow from the wagon to the receiving tank, a small dipper holding any definite quantity, say 0.5 liter (about 1 pint) is filled from the stream of oil. Similar samples are taken at equal intervals of time from the beginning to the end of the flow—a dozen or more dipperfuls in all. These samples are poured into a clean drum and well shaken. If the oil is heavy, the dipperfuls of oil may be poured into a clean pail, and thoroughly stirred. For a complete analysis the final sample should contain at least 4 liters (about 1 gallon). This sample should be poured into a clean can, soldered tight and forwarded to the laboratory.

It is important that the dipper be filled with oil at uniform intervals of time, and that the dipper be always filled to the same level. The total quantity of oil taken should represent a definite quantity of oil delivered and the relation of the sample to the delivery should be always stated, for instance: "1-gallon sample representing 1 wagon-load of 20 barrels." A careful examination should be made for water, and if the first dipperful shows water this dipperful should be thrown into the receiving tank and not mixed with the sample for analysis.

Instead of taking samples with a dipper, it may be more convenient to take a continuous sample. This may be taken by allowing the oil to flow at a constant and uninterrupted rate from a ½-in. cock on the under side of the delivery pipe during the entire time of discharge. The continuous sample should be thoroughly mixed in a clean drum or pail, and at least 4 liters (about 1 gallon) of it forwarded for analysis.

OIL VS. COAL

Aside from price conditions, the advantages claimed for oil are as follows:

The cost of handling and storage is low, and there is no deterioration or danger in storage, under proper conditions. Oil can be stored some distance from the boilers, and occupies 50% less space and has 25% less weight for equal heat value, as compared to coal.

More perfect combustion is obtainable, since the air can be better controlled, and there is no loss of combustible in ash, nor interruptions for cleaning.

The intensity of the fire can be instantly regulated to meet fluctuating loads, giving a high degree of flexibility. Demands for power can be met

in a few minutes, in standby plants used to supplement hydro-electric equipment, and steam is kept up for hours without fuel, or with a very limited supply, saving the cost of banking fires.

One man can attend eight or twelve boilers. In large plants this means a considerable reduction in labor costs, and firemen do not have to be chosen on the basis of physical strength. It is possible to run in ordinary operation with practically "test" conditions.

Oil can be burned without dirt and dust or smoke, saving wear on machinery and nuisance to surrounding property, and a smaller stack is required.

Tending against the adoption of oil burners are the damage to improperly proportioned furnaces and boilers, and the cost of changing over or of new equipment, with the possibility of discontinuance of supply at a reasonable price. Careful investigation must also be made of the effects of insurance restrictions or local ordinances on the storage problem.

Charles L. Hubbard states that in a small plant the number of men employed will not vary much with the two kinds of fuel, but that in a large oil-fired plant one man will do the work of four to six men in a corresponding coal-fired plant

F. H. Daniels stated in 1924 that stokers and auxiliary equipment ranged in cost from $.80 to $1.40 per sq ft of boiler heating surface, and coal-and ash-handling equipment 60 to 80c per sq. ft., while fuel oil requires storage tanks, oil pumps, heaters and burners, costing from $1 to $3 per sq. ft., depending on the amount of reserve storage. For a central station of 50,000 sq. ft. boiler heating surface, the complete oil-burning equipment with storage tanks for five months' supply has been estimated at $250,000, or $5 per sq. ft., although an industrial plant could get along on much less storage. For equal calorific values, fuel oil occupies only about two-thirds of the storage space required for coal, but as oil tanks must be separated, the land area is about the same as for coal. Fuel oil leaves no ashes to be removed, but steam soot blowers must be used four or five times a day.

Probable costs should be estimated on a heat-content basis, or rather on a heat-available basis, also taking into consideration handling and standby savings, etc. *Philip E. Hambsch* states that the average evaporation from 18,500 BTU oil is 15 pounds per lb., while that from ordinary coal is 7.5 pounds per lb., so that oil can be roughly assumed to be worth twice as much thermally, pound per pound. A barrel of oil (42 gallons of about 8 pounds each) averages in weight 336 pounds, 3 barrels of oil (1008 pounds) can on this basis be taken roughly equal to a ton of coal, so that oil at $1.50 or less per barrel can compete with coal at $4.50 per ton. More conservative estimates call for 3½ to 4½ barrels of oil to equal 1 ton of coal, and on the latter basis the price of oil, in cents per gallon, should be one-half that of coal in dollars per ton; that is, oil would have to be at 2¼ct. to meet coal at $4.50.

If the actual heating values of the two fuels are known, the possibilities can be figured on a more accurate basis. Efficiencies of 75 to 85% have been secured over long periods with oil, and in general, considering

higher efficiency and reduced labor costs, oil can be economically burned at prices in excess of those asked for coal, on a *BTU* content basis.

Charles E. Lucke gives the chart on page 128 for determining in cents per million *BTU*, the cost of heat in fuel oil, from the Baumé reading, cost per gallon and heat content. The chart below, for coal, is also by him.
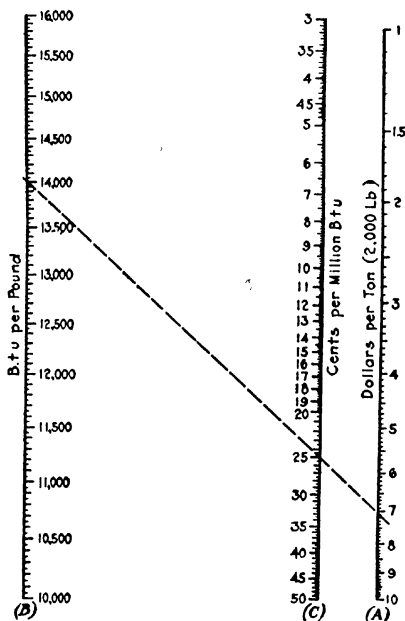
Cost of Energy of Solid Fuel in Cents per Million B.t.u.

$$\text{Cents per million B.t.u.} = \frac{\text{Dollars per ton} \times 100 \times 1{,}000{,}000}{\text{B.t.u. per lb.} \times 2{,}000} = (C) = \frac{(A)}{(B)}$$

Example: Dollars per ton=7; B.t.u. per lb.=14,000

$$\therefore \text{Cents per million B.t.u.} = \frac{7 \times 100 \times 1{,}000{,}000}{14{,}000 \times 2{,}000} = 25$$

By Chart: (A)=7; (B)=14,000; ∴ (C)=(A)/(B)=25 (check)
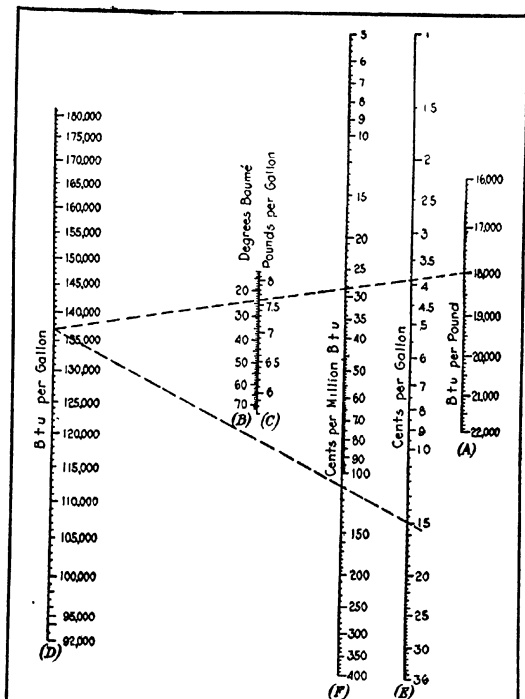
Cost of Energy of Liquid Fuel in Cents per Million B.t.u.

$$\text{Lb per gal} = \frac{140 \times 8.33}{130 + \text{Deg. Bé.}} = (C) = (B)$$

B.t.u. per gal. = B.t.u per lb. × lb. per gal. = (D) = (A) × (C)

$$\text{Cents per million B.t.u.} = \frac{\text{Cents per gal.} \times 1{,}000{,}000}{\text{B.t.u. per gal.}} = (F) = \frac{(E)}{(D)}$$

EXAMPLE: Deg. Bé = 23.5; B.t.u. per lb. = 18,000; cents per gal. = 15
Lb. per gal. = (140 × 8.33)/(130 + 23.5) = 7.6
B.t.u. per gal. = 18,000 × 7.6 = 137,000

$$\text{Cents per million B.t.u.} = \frac{15 \times 1{,}000{,}000}{137{,}000} = 110$$

By Chart: (B) = 23.5 or (C) = 7.6; (A) = 18,000; (E) = 15
  First step: (D) = (A) × (C) = 137,000
  Second step: (F) = (E)/(D) = 110 (check)

C. H. Delany gives the following comparisons of fuel oil with coal of various grades. The data as to fuel required for a given steaming effect are in each case based on the average efficiency secured in practice with such fuels. The coal is assumed to contain 6% moisture as received, and the oil 1%.

	Coal						Oil
BTU per lb. dry fuel	10,000	11,000	12,000	13,000	14,000	15,000	18,500
Boiler efficiency, per cent.	60	63	66	69	72	75	78
Dry fuel, per boiler H.P., lb.	5.58	4 82	4 22	3 73	3.32	2.97	2.32
Fuel as fired per boiler H.P., lb.	5.94	5.13	4.49	3 97	3 53	3.16	2.34
Coal equivalent to 1 bbl. oil (42 gal.), lb.	851	737	645	570	506	454	...
Price of 1 ton (2000 lb.) of coal equivalent to oil at $2 per bbl.	$4.70	$5.43	$6.20	$7.03	$7.92	$8.82	...
Price of 1 bbl. of oil equivalent to coal at $5 per ton	$2.13	$1.84	$1.61	$1.42	$1.26	$1.13	...

In this the cost of the two fuels is considered, without regard to the relative cost of equipment or labor.

GASEOUS FUELS

Boilers fired with natural or artificial gas possess all the advantages of oil-burning installations as to cleanliness, ease of control and low labor charge, and but few of the disadvantages. The production of gas especially for steam purposes offers no great advantages economically, although waste gases from blast furnaces and coke ovens are becoming more widely used for burning under boilers as well as being used directly in internal combustion engines.

Natural gas, like mineral oil, is formed from organic matter, and is chiefly a mixture of hydrocarbons, and rather simple in its composition, as there are few hydrocarbons which are gaseous at ordinary temperatures. It consists almost entirely of methane or marsh gas, CH_4, with traces of CO, CO_2, oxygen and nitrogen. Some natural gases contain higher hydrocarbons, such as ethylene, C_2H_4, which give illuminating value or which can be condensed by compression and removed. Consisting almost entirely of carbon and hydrogen, the natural gases have considerable heating value, even when figured on the so-called "low" basis, where the latent heat of vaporization of the water produced is deducted. This heat does not become available till the products of combustion are cooled below saturation temperature, which is done in the calorimeter test, but does not occur in boiler practice. The average low calorific value is 21,000 *BTU* per lb. of gas.

Coke oven gas contains over 80% of hydrogen and hydrocarbons distilled off from the coked coal, and has a heating value (low) of 14,000 *BTU* per lb. It is particularly suitable for firing water-tube boilers, and with proper combustion arrangements evaporations of 5½ lb. per hr. per sq. ft. of heating surface can easily be obtained at highest efficiency. It is produced by carbonizing coal in by-product coke ovens.
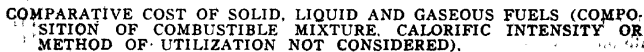
COMPARATIVE COST OF SOLID, LIQUID AND GASEOUS FUELS (COMPO-
SITION OF COMBUSTIBLE MIXTURE, CALORIFIC INTENSITY OR
METHOD OF UTILIZATION NOT CONSIDERED).
                                        —W. S. Rockwell Co.

Blast furnace and producer gases contain around 60% atmospheric nitrogen, with quantities of CO and CO_2. Blast furnace gas is formed in the process of reducing iron ore by the combustion of coke in an atmosphere lean in oxygen. The CO thus resulting from the primary combustion of the coke in the hearth is partly oxidized to CO_2 by the descending ore, but sufficient CO remains in the gas to give it a heating value of over 1200 BTU per lb., and to make it available, when cleaned and dried, for combustion in pre-heating stoves or under boilers

Producer gas is generated by passing a current of air, or air and steam, through a thick layer of incandescent coal surmounted by freshly charged coal. The solid fuel is thus converted into a combustible gas, containing CO, hydrogen and methane, the residue being treated as refuse. This process does not pay, as compared with burning the coal directly, unless the most careful and efficient combustion arrangements are provided. With a producer turning out 75% of the heat of the coal in the gas, and 75% efficient utilization of the gas, the steaming results will approximate those from solid coal fuel, and the by-products will yield some profit.

The calorific value of a gas can be more readily predicted than that of coals and oils, since each of its constituents has a known calorific power. The calorific value per unit volume is the sum of the proportions by volume of each of the constituents multiplied by their calorific powers per unit volume. There will be both a high and low calorific value, owing to the presence of hydrogen. The accompanying table shows the compositions and calorific values of representative natural, blast furnace, producer, and by-product coke gases

TYPICAL VOLUMETRIC ANALYSES AND COMBUSTION CHARACTERISTICS
OF FUEL GASES
(C. E. Lucke)

	CO	H_2	CH_4	C_2H_4	C_6H_6	O_2	CO_2	N_2	BTU per lb.
Natural Gas (Kansas).	.25		98.2		1	.25			21301
Coke Oven Gas.	6.0	42.0	34.3	2.0	2.0	1.1	2 5	10.1	14384
Blast Furnace Gas....	27.5	3 0					10.0	59.5	1274
Anthracite Producer ...	25.7	15.3	.2			.40	5.5	52.9	1929
Bituminous Producer ..	14.34	2.81	5.56			.10	10.5	66.7	1397

	Sp. Wt. lb per cu. ft.	Sp. Vol cu. ft. per lb	Theoretical Air for Combustion		"Low" Htg. Value	
	At 32° F. and 29.92" Hg.		cu. ft per cu. ft.	lb per lb	BTU per lb.	BTU per cu. ft.
Carbon Monoxide CO..	.07807	12.8090	2.39	2.470	4369	341
Hydrogen H_2	.00562	177.9093	2.39	34.320	51892	292
Methane CH_4	.04470	22.3490	9.56	17 244	21463	959
Ethylene C_2H_4	.07951	12.5780	14.34	14.557	20053	1595
Benzene C_6H_6	.21930	4.5600	35.85	13.194	17305	3795
Natural Gas (Kansas)..	.04460	22.4200	9.397	17.004	21301	950
Coke Oven Gas.........	.04031	24 8070	5.43	10.872	14384	580
Blast Furnace Gas.....	.08049	12.4239	.729	.731	1274	103
Anthracite Producer ..	.06954	14.3810	.999	1.159	1929	134
Bituminous Producer ..	.07902	12.6540	.937	1.059	1397	110
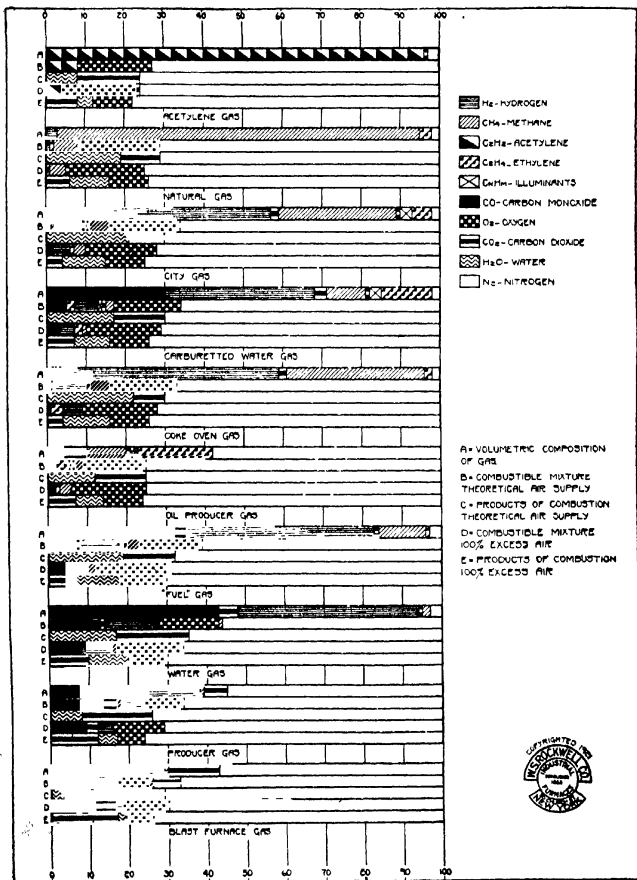
VOLUMETRIC COMPOSITION OF INDUSTRIAL GASES, AND OF
COMBUSTIBLE MIXTURES AND PRODUCTS OF COMBUSTION OF SAME

COMPOSITION, ENERGY CONTENT AND CALORIFIC INTENSITY OF INDUSTRIAL GASES (FURNACE DESIGN AND OPERATION NOT CONSIDERED).

—*W. S. Rockwell Co.*

The charts on pages 132 and 133, by *W. S. Rockwell Co.,* give the combustion characteristics of industrial gases. While there is a great difference in the *BTU* value of the gases, there is relatively little difference in the products of combustion, although the difference in chemical composition of two mixtures having substantially the same *BTU* value will frequently affect the economical results and hence dictate the choice of fuel for certain operations, regardless of comparisons on a *BTU* basis.

The chart on p. 130, by *W. S. Rockwell Co.,* gives the cost per million *BTU* in the fuel for solid fuels, oils and gases, also the cost per million *BTU* when using electrical energy in industrial furnaces. If the $5.00 per ton line is followed from the bottom to the 12,000 *BTU* coal diagonal, it is seen that coal of this description represents a cost of 21c. per million *BTU*. If the 21c. cost line is followed to the fuel-oil diagonal, 142,000 *BTU* per gal., the equivalent oil price is found to be 3c. per gal. (The gas values are in *BTU* per cu. ft., the solid fuels in *BTU* per lb.) This chart does not consider the adaptability of the fuel from the physical or chemical standpoint, nor the type of apparatus required for its utilization, which are important additional factors in most applications.

Section II—Combustion

Combustible.—The portion of a fuel which combines with oxygen is the *combustible*. In steam practice, the term combustible is applied to that portion of the fuel remaining after subtracting moisture and ash. Thus it may include some oxygen and nitrogen.

Perfect Combustion.—Combustion is perfect when the combustibles unite with the greatest possible amount of oxygen; in the case of carbon, when it burns to CO_2. Combustion is imperfect when complete oxidation of the combustible does not occur; that is, in the case of carbon, when it burns to CO.

The combustion of 1 lb of carbon (C) by means of pure oxygen (O_2) to carbon dioxide (CO_2) generates $3\frac{2}{3}$ lb. of gas and liberates 14,544 BTU.

The combustion of 1 lb C to CO_2 by means of air generates 12.52 lb. of gas, the excess over $3\frac{2}{3}$ lb. consisting of inert nitrogen (N_2).

The combustion of 1 lb. C to carbon monoxide (CO) by means of pure oxygen generates $2\frac{1}{3}$ lb. of gas and liberates 4351 BTU.

The combustion of CO to CO_2 liberates $14,544 - 4351 = 10,193$ BTU per lb. of *carbon* involved, or $\dfrac{12}{12 + 16} \times 10,193 = 4368$ BTU per lb. of CO.

When CO_2 is reduced to CO, it takes up an additional atom of C to form two molecules of CO. The reduction absorbs $14,544 - (2 \times 4351) = 5842$ BTU per lb. of carbon in the CO_2 or $5842/2 = 2921$ BTU per lb. C in the CO produced.

When H_2 and O_2, at 212° F, combine to form water vapor at 212° F., the heat of combustion, commonly known as the "low value," is 51,892 BTU per lb. of hydrogen. If the vapor were condensed to water at 212° F., the heat liberated would be the "high value," 60,626 BTU. If the gases were initially at 64° F., and the vapor is condensed to water at 64° F., the value would be 61,200 BTU. From 1 lb. hydrogen and 8 lb. oxygen, 9 lb. water results.

The dissociation of 1 lb. of water (H_2O) to H_2 and O_2 absorbs

$$\frac{2}{2 + 16} \times 60,626 = 6736 \ BTU,$$

at an initial and final temperature of 212° F.

The calculation of the maximum temperature obtainable by burning a given fuel obviously depends upon the heat capacity of the products of com-

bustion. It cannot be calculated by dividing the total heat introduced into and liberated in the furnace with the fuel and air of combustion by any one value of the specific heat of the products of combustion multiplied by their weight, since the specific heat varies with temperature. A better method is to use the total heat capacities of the products of combustion at various temperatures, as in the method of page 176.

AIR THEORETICALLY REQUIRED FOR COMBUSTION

The study of combustion requires a knowledge of the properties of air. Air is a mechanical mixture of 20.91% oxygen and 79.09% nitrogen by volume. By weight, air contains 23.15% oxygen, and 76.85% nitrogen. In nature, besides oxygen and nitrogen, air contains carbon dioxide, dust, ozone, water vapor and other gases in slight amounts.

The weight and volume of air can be computed from the formula

$VP = 53.4T$, wherein

V = volume in cu. ft. of 1 lb. of air.

P = absolute pressure in lbs. per $sq. ft.$ (atmospheric pressure = 14.7 lb. per $sq. in.$)

T = absolute temperature, Fahr., = temperature Fahr. + 459.6.

$1/V$ = weight of 1 cu. ft. of air.

By changing the constant, this formula can be used for other gases, 48.24 for oxygen, 54.97 for nitrogen, 765.71 for hydrogen, 35.09 for CO_2, 55.14 for CO and 24.10 for SO_2. The table below, for air, is computed from this formula.

VOLUME AND WEIGHT OF AIR AT ATMOSPHERIC PRESSURE (14.7 LBS. PER SQUARE INCH) AT VARIOUS TEMPERATURES.—*From Steam.*

Temperature Degrees Fahrenheit	Volume One Pound in Cubic Feet	Weight One Cubic Foot in Pounds	Temperature Degrees Fahrenheit	Volume One Pound in Cubic Feet	Weight One Cubic Foot in Pounds	Temperature Degrees Fahrenheit	Volume One Pound in Cubic Feet	Weight One Cubic Foot in Pounds
32	12.390	.080710	160	15.615	.064041	340	20.151	.049625
50	12.843	.077863	170	15.867	.063024	360	20.655	.048414
55	12.969	.077107	180	16.119	.062039	380	21.159	.047261
60	13.095	.076365	190	16.371	.061084	400	21.663	.046162
65	13.221	.075637	200	16.623	.060158	425	22.293	.044857
70	13.347	.074929	210	16.875	.059259	450	22.923	.043624
75	13.473	.074223	212	16.925	.059084	475	23.554	.042456
80	13.599	.073535	220	17.127	.058388	500	24.184	.041350
85	13.725	.072860	230	17.379	.057511	525	24.814	.040300
90	13.851	.072197	240	17.631	.056718	550	25.444	.039302
95	13.977	.071546	250	17.883	.055919	575	26.074	.038353
100	14.103	.070907	260	18.135	.055142	600	26.704	.037448
110	14.355	.069662	270	18.387	.054386	650	27.964	.035761
120	14.607	.068460	280	18.639	.053651	700	29.224	.034219
130	14.859	.067300	290	18.891	.052938	750	30.484	.032804
140	15.111	.066177	300	19.143	.052239	800	31.744	.031502
150	15.363	.065092	320	19.647	.050898	850	33.004	.030299

To determine the weight per cu. ft. of air or flue gases at a pressure of 29.92 in. mercury, but at other temperatures than $32°$ F., use for air weight per cu. ft. $= .0807 \dfrac{492}{T°}$ and for flue gases $.084 \dfrac{492}{T°}$, wherein $T°$ is the absolute temperature Fahr.

One pound of pure carbon requires for its combustion 2.67 lb. of oxygen, or 32 cu. ft. at 60° F. The gaseous products of combustion, when cooled, will occupy the same volume as the original oxygen, namely 32 cu. ft., and will weigh 3.67 lb. Nitrogen in air used for combustion undergoes no change and occupies its original volume.

The table on page 139, from *Steam*, gives the weights of oxygen and air theoretically required for the combustion of the combustible constituents of coal. As an example of the calculation of these quantities, consider the reaction
$$C + O_2 = CO_2.$$
$$\text{Molecular weights } 12 + 32 = 44.$$
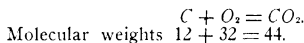
1 lb. of C requires $32/12 = 2\frac{2}{3}$ lb. of O to form $44/12 = 3\frac{2}{3}$ lb. of CO_2. Ratio N/O in air $= 3.32$, therefore the nitrogen accompanying the oxygen of air required to burn one pound of carbon is $2\frac{2}{3} \times 3.32 = 8.85$ lb., and the total weight of air for 1 lb. of carbon is 11.52 lb.

The table also gives the heat energy generated by the complete combustion of one pound of the combustible constituents.

The theoretical amount of air required for the complete combustion of coal can be computed from the formula

Weight of air per lb. of coal $= 11.52C + 34.56[H - (O/8)] + 4.32S$. C, H, O and S are the proportional parts by weight of carbon, hydrogen, oxygen and sulphur from the ultimate analysis of the coal

Hydrogen combines with eight times its weight of oxygen, therefore it is assumed that hydrogen equivalent in weight to one-eighth of the oxygen in coal will not require oxygen from the air.

The following slightly different formula is used by the *Bureau of Mines* for computing the air theoretically required for burning one pound of combustible:
$$A = 34.48H + 11.58C + 4.336\ (S - O)$$

H, C, S and O are proportions based on coal free from moisture and ash. These formulæ are somewhat inexact, because they contain no correction for the nitrogen in the coal.

Complete combustion is not obtained in boiler furnaces receiving only the amount of air theoretically required. 30 to 50% above that theoretically required, or altogether 16 to 18 lb. of air per pound of fuel, is necessary to insure perfect combustion, but in only a very few plants is the air supply maintained at this point. It is often found to run from 100 to 200 or 400% excess, entailing great loss of heat in the hot chimney gases.

V. J. Azbe points out the inaccuracy of the current statement that approximately 12 lb. of air are theoretically required per pound of *coal*. The table given below shows that one coal may require only 7 lb. of air, while another would require 11.2 lb. of air per pound. However, with different coals approximately the same quantity of air is required for liberating a given quantity of heat. He suggests the expression "pounds of air per 10,000 *BTU*." Coal requires something over 7½ lb. of air per 10,000 *BTU* liberated.

AIR REQUIRED FOR DIFFERENT FUELS

	Air theoretically required per lb. of coal	per 10,000 *BTU* generated
Illinois bituminous, poor quality.........	7 0	7.6
Illinois bituminous, good quality.......	9 4	7.55
Anthracite, average	10.2	7.65
Semi-bituminous, Pocahontas	11.2	7.5
Liquid fuel	14.24	7 04

Available Hydrogen Lb Various Fuels	
Wood	0 1%
Peat	1-1 5%
Lignite	15 20%
Bituminous Coal	3-4%
Semi-Bituminous Coal	4-5%
Anthracite Coal	15-25%
Fuel Oil	9-14%
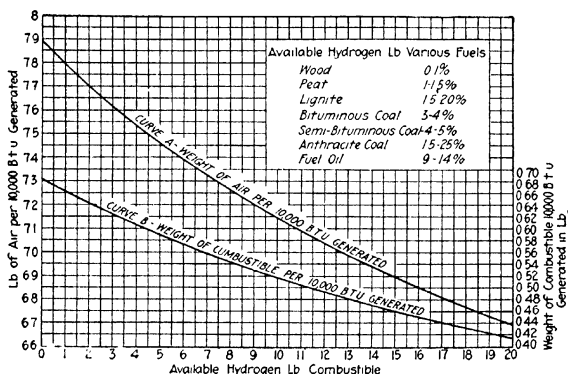
1. THEORETICAL AIR AND COMBUSTIBLE PER 10.000 *BTU*
   —*U. S. Geol. Survey.*

Curve *A* in Figure 1 shows the weight of air required to generate 10,000 *BTU* with fuels of different hydrogen content. The abscissæ are % of available hydrogen per lb. of combustible. The available hydrogen is the % of hydrogen less one-eighth of the % of oxygen. This, divided by the % of combustible, is equal to the % available hydrogen per lb. of combustible. The % available hydrogen per lb. of combustible in com-

OXYGEN AND AIR REQUIRED FOR COMBUSTION, AT 32° F AND 29.92 IN.
OF MERCURY AIR PRESSURE.—*Steam.*

BY WEIGHT

1	2	3	4	5	6	7	8	9	10
Oxidizable Substance or Combustible	Chemical Symbol	Atomic or Combining Weight	Chemical Reaction	Product of Combustion	Oxygen per Pound of Column 1 Pounds	Nitrogen per Pound of Column 1 = 3½* x O Pounds	Air per Pound of Column 1 = 4 32 † x O Pounds	Gaseous Product per Pound of Column 1 = Columns 1 + 8 Pounds	Heat Value per Pound Column 1 B.t.u.
Carbon	C	12	$C+2O=CO_2$	Carbon Dioxide	2 667	8 85	11 52	12 52	14600
Carbon	C	12	$C+O=CO$	Carbon Monoxide	1 333	4 43	5 76	6 76	4450
Carbon Monoxide	CO	28	$CO+O=CO_2$	Carbon Dioxide	571	1 90	2 47	3 47	10130‡
Hydrogen	H	1	$2H+O=H_2O$	Water	8	26 56	34 56	35 56	62000
Methane	CH₄	16	$CH_4+4O =$ CO_2+2H_2O	Carbon Dioxide and Water	4	13 28	17 28	18 28	23550
Sulphur	S	32	$S+2O=SO_2$	Sulphur Dioxide	1	3 32	4 32	5 32	4050

BY VOLUME

1	2	11	12	13	14	15	16	17	18
Oxidizable Substance or Combustible	Chemical Symbol	Volumes of Column 1 Entering Combination Volume	Volumes of Oxygen Combining with Column 11 Volume	Volumes of Product Formed Volume	Volume per Pound of Column 1 in Gaseous Form Cubic Feet	Volume of Oxygen per Pound of Column 1 Cubic Feet	Volume of Products of Combustion per Pound of Column 1 Cubic Feet	Volume of Nitrogen per Pound of Column 1 3½§ x Column 15 Cubic Feet	Volume of Gas per Pound of Column 1 = Column 16+Column 17 Cubic Feet
Carbon	C	1C	2	2CO₂	14 95	29 89	29 89	112 98	142 87
Carbon	C	1C	1	2CO	14 95	14 95	29 89	56 49	86 38
Carbon Monoxide	CO	2CO	1	2CO₂	12 80	6 40	12 80	24 20	37.00
Hydrogen	H	2H	1	2H₂O	179 32	89 66	179 32	339 09	518 41
Methane	CH₄	1C 4H	4	1CO 2H₂O	22 41	44 83	67 34	169 55	236.89
Sulphur	S	1S	2	1SO₄	5 60	11 21	11 21	42 39	53 60

* Ratio by weight of O to N in air
† 4 32 pounds of air contains one pound of O.
‡ Per pound of C in the CO.
§ Ratio by volume of O to N in air.

(The chemistry of columns 4, 11 and 12 above is open to question, as C is not a gas and it is not proper to speak of its volume as a gas, hydrogen gas exists as H_2 not as H, and oxygen as O_2, not O.—Ed.)

mercial coals runs from about 2½ to 5. The calculations for the curve disregard sulphur, since its percentage is small. Curve B gives the weight of combustible to generate 10,000 BTU. The weight of air theoretically required per lb. of fuel can be obtained by multiplying the heating value of the fuel by the weight of air theoretically required to generate 10,000 BTU, as obtained from the curve, and dividing by 10,000.

Mass Action.—The necessity for excess air is partially occasioned by inadequate mixing of the air with the combustible, but also by the appreciable time required for combustion, as explained by the law of mass action. This firmly established and useful law of physical chemistry may be illustrated by the fact that the more water used, the easier it is to dissolve sugar or salt. The law of mass action states that the speed of any chemical reaction is proportional to the product of some powers of the weights expressed in gram molecules of the reacting substances present in unit volume. A gram molecule is a weight numerically equal in grams to the molecular weight of the substance, and the number of gram molecules in a given volume of a substance would be the weight in grams divided by the molecular weight.

The speed of a chemical reaction increases when the weight in gram molecules of the reacting substance in a unit volume increases, although the relation may not be a simple proportion. If there are two molecules of carbon monoxide and ten molecules of oxygen in a unit volume, the chances of one molecule of oxygen meeting the two molecules of carbon monoxide are a great deal more than if there were only one or two molecules of oxygen in the same unit of volume. When, in the mixture of air and furnace gases, some of the oxygen unites with carbon monoxide, this oxygen is no longer available for oxidizing the remaining combustible The products of combustion are in the way and fewer oxygen and carbon monoxide molecules are left, so that the molecules of oxygen meet the molecules of combustible gas less frequently. As the combustion proceeds, the masses of free oxygen and combustible gas become less and less compared with the total mass of gas present, and their combination becomes slower until it is nearly zero. Were the air supply in the ordinary furnace limited to the theoretical amount, the reaction would take so long, assuming the present gas mixing arrangements, that the gases would have passed through the furnace before completing combustion.

Fifty-six parts by weight of carbon monoxide (twice its molecular weight) combine with 32 parts by weight of oxygen (its molecular weight), two molecules of carbon monoxide and one molecule of oxygen combining to form two molecules of carbon dioxide The weights of equal volumes of gases are directly proportional to their molecular weights, as the same volume of all gases at the same temperature and pressure contains the same number of molecules. In applying the law of mass action, by substituting the volumetric percentages of the substances, as ordinarily given in gas analyses, in the mass-action equation corresponding to the particular reaction, we obtain a relative indication of the rate of combustion, assuming the same pressure and the same temperature in every case. For the combining of CO with O_2, the relative rate of combustion is given by the equation

$$\text{rate of combustion} =$$
$$\text{constant} \times (\text{gram molecules of } CO \text{ per cu. meter})^2 \times (\text{gram molecules of } O_2 \text{ per cu. meter}).$$

By taking the analyses of gases from different points in the gas passage, from the fuel bed to the end of the combustion chamber, the relative rates of combustion at the different points in the combustion chamber can be determined.

However, calculations of velocities of reaction based on the laws of mass action are liable to be seriously in error owing to disturbing side reactions. If more than one combustible is present, the two reactions go on independently side by side and the effects are added. Care must be taken not to add these velocity products without having first multiplied each by its proper reduction factor, which for most substances is imperfectly known for high temperatures. Therefore it is not feasible at present to get an expression for the absolute total velocities of combustion for all constituents taken together at several points along the flame.

The law of mass action also applies to the combustion of the fixed carbon on the grate. The mass of solid carbon is almost infinite in comparison with that of the gaseous oxygen, so that the velocity of combustion depends to a large extent upon the rate of diffusion. That is, there is a layer of CO next to the carbon, and combustion can take place only so fast as this can be reached by O_2. Part of the resulting CO_2 escapes and part breaks down to CO again by contact with the hot carbon. Scrubbing action, due to the velocity of the gases, promotes the interchange of O_2 and CO_2 and accelerates the combustion; note for example how much more rapidly coal burns at a thin spot or over the end of a tuyere where the air velocity is great. Obviously diffusion plays a part in the combustion of both gases and solids.

The speed of chemical reactions also increases at a rapidly increasing but not definitely known rate as the temperature is increased. There is some combustion even at ordinary atmospheric temperatures, which, if the resulting heat is confined, may cause a high temperature and give rise to so-called spontaneous combustion. At high furnace temperatures, the rate of combustion is enormously increased for both gases and solids.

H. D. Fisher discusses the effect of supplying oxygen or enriched air to the furnace if this should become economically feasible. He states that the firebox would have to consist of water-cooled surfaces, while radiation from the hot flames to the boiler tubes would reduce the gases to a temperature approximating that of present boiler practice before entering the passes; that the tube surface could be reduced to one-third or one-fifth of that now required, and that the gases would carry off only one-fifth as much heat, due to reduction in volume.

GRATES AND GRATE SURFACE

The purpose of the grate is to support the fuel bed, while at the same time admitting air for combustion. It should be so designed that it will be kept uniformly cool by the inflow of air and that it will void ashes freely at all points. The width of air space is determined by the coal for which the grate is to be used. It should be as wide as possible while not allowing the coal to drop through.

Authorities differ as to the proper width of air space. Gebhardt says that for average bituminous coal the air space should be ⅝ in. wide, and the bars ¾ in. Air openings in grate bars should be ³⁄₁₆ in. wide for No. 3 buckwheat, and ⁵⁄₁₆ in. for No. 1 buckwheat. It is important that they be uniformly distributed, to avoid blowing holes in the fire.

The physical ability of the fireman limits the depth of the grate surface for hand firing. The handling of a soft coal fire is more difficult, and therefore the grates cannot be as deep as for anthracite. Grates 10 to 12 feet deep, with a slope of 1½ in. per foot, can be handled with buckwheat.

Grate area has usually been determined arbitrarily in proportion to the heating surface of the boiler; that is, for a given size of coal the heating surface and the grate surface have had a fixed ratio. The following figures for anthracite and the table for bituminous coal are given to show usual practice.

A ratio of grate surface to heating surface of 1 to 35 or 40 will develop the rated capacity of the boiler when burning buckwheat. For finer sizes, or for overloads, the ratio should preferably be 1 to 25, and forced draft should be used.

The following table is given by *Marks* for the grate proportions for burning various bituminous coals:

Coal	Grate bar openings Mine run	Slack	Ratio for economy Mine run	Slack	Ratio for capacity Mine run	Slack
Va., W. Va., Md., Pa.......	½	⅜	1:60	1:55	1:55	1:50
Ohio, Ky., Tenn., Ala.......⅜—½		¼	1:55	1:50	1:50	1:45
Ill., Ind., Kan., Okla........⅜—½		¼	1:50	1:45	1:45	1:40
Col. and Wyo..............	⅜	¼	1:50	1:45	1:45	1:40

V. E. Holyoke has prepared a chart, page 143, of recommended grate sizes for hand firing. In general bituminous coal is best served by shaking grates since agitation of the fuel bed assists in freer passage of air through the fuel. Anthracite can be handled best on dumping grates, since it burns better without agitation. Under certain conditions, however, a combination shaking and dumping grate will serve to good advantage under the smaller sizes of anthracite. The size of coal determines the size of mesh to be used. The free air space for hard coal is limited to a maximum of about 30%, while that for soft coal ranges from 25 to 50%. Soft coal can be retained upon a grate with a wider opening because of the bridging action of this fuel.

Many industrial plants use soft coal on shaking grates, but when these plants come within the limits of areas restricted to the use of hard coal, for smoke prevention, the chances are that dumping grates are used. Dumping grates are more successful in high-pressure plants where expert firemen and licensed engineers are employed who can give constant attention to the furnaces. In smaller plants operating under low pressure, a combination shaking and dumping grate is often used with satisfactory results. The grate area for the development of a definite boiler output must be larger for anthracite coal than for bituminous. A simple check on the grate area for nominal boiler ratings can be made with the use of the following table:

RELATION OF GRATE SURFACE TO BOILER HEATING SURFACE

For No. 1 Buckwheat ....1 to 40 sq. ft.
For No. 2 Buckwheat ....1 to 35 sq. ft.
For No. 3 Buckwheat ....1 to 30 sq. ft.
For No. 4 Buckwheat ....1 to 25 sq. ft.
For high-grade bituminous ....1 to 55 sq. ft.
For medium-grade bituminous ....1 to 50 sq. ft.
For low grade bituminous ....1 to 45 sq. ft.

SPECIFICATION TABLE FOR GRATES FOR BOILER FURNACES

Kind of Coal	Service	Kind of Plant	Type of Grate	Size of Coal	Size of Mesh, Inches	% Free Air Space, Approx	Kind of Draft
Bituminous	High Pressure	Industrial	Shaking	(Soft coal) run of mine...	3/8	43	These grate meshes will work satisfactorily under natural draft. Forced draft may be used without change of grates where over rating of boiler is desired
				slack	1/4	35	
		Heating	Shaking	(Soft coal) run of mine.	3/8	43	
				slack	1/4	35	
	Low Pressure	Heating	Shaking	(Soft coal) large brick set boilers	3/8	43	
					1/4	35	
			Shaking and dumping	(Soft coal) fire-box type of boiler	3/8	44	
					1/4	38	
Anthracite	High Pressure	Industrial	Dumping	No. 1 buckwheat	1/4	32	Natural
				No. 2 buckwheat	1/4	19	Forced
				No. 3 buckwheat	3/32	32	Strong Natural
				Culm	3/64	12	Forced
						7	Forced
		Heating	Dumping	No. 1 buckwheat	1/4	32	Natural
				No. 2 buckwheat	1/4	19	Forced
				No. 3 buckwheat	1/4	32	Strong Natural
				Culm	3/64	12	Forced
						7	Forced
	Low Pressure	Heating	Shaking and dumping	Pea	3/8	44	Natural
				No. 1 buckwheat	1/4	38	Natural
				No. 2 buckwheat	5/32	29	Forced
				No. 2 buckwheat	1/4	38	Strong Natural
			Shaking and dumping	Pea	3/8	44	Natural
				No. 1 buckwheat	1/4	38	Natural
				No. 2 buckwheat	5/32	29	Forced
				No. 2 buckwheat	1/4	38	Strong Natural

The comparatively small difference in the amount of fixed carbon burned per unit of grate surface with all kinds of coal under equal operating conditions is surprising. *A. A. Cary* prefers to burn from 12 to 16 lb. of fixed carbon per sq. ft. of hand-fired grate surface per hour, with chimney draft. Roughly the rates of combustion for different fuels would be:

> Anthracite, 15 lb. per sq ft per hour.
> Semi-anthracite, 16 lb. per sq. ft. per hour.
> Semi-bituminous, 18 lb per sq. ft. per hour.
> Eastern bituminous, 20 lb. per sq. ft. per hour.
> Western bituminous, 30 lb. per sq. ft. per hour.

In determining the amount of grate surface to be used with a given amount of heating surface, the draft available must be considered as well as the coal. The curves given on page 201 show how much draft is necessary for burning different coals at different rates of combustion.

The draft required to overcome the resistance of any type of boiler is also known fairly closely (see page 203). This must be subtracted from the total draft available, to determine the draft available for the fuel bed. For any given type of boiler the overall efficiency can be approximately assumed. Knowing the capacity of the boiler, the number of heat units, and therefore the number of lb. of a given coal required per hour, can be obtained. Dividing the number of lb. of coal which must be burned per hour by the rate of combustion taken from the curve, gives the total grate area required in square feet.

HAND FIRING

There are two general methods of hand firing:

In the Spreading Method, sometimes called the alternate method, a small amount of coal is fired at one time, and spread evenly over the fuel bed from the front to rear. The firing is done alternately through the fire doors, so that the entire fire is not blanketed with green coal. Hand firing practice leans more and more to spread firing. In some tests on a furnace equipped with three firing doors, the *Bureau of Mines* used the following spreading method: The rear half of the section of grate fired through doors 1 and 3 and the front half of the section fired through door 2 were fired at the same time. At the next firing, the front half of the section of grate fired through doors 1 and 3 and the rear half of that fired through door 2 were fired.

In the Coking Method, fresh coal is fired at considerable depths at the front of the grates, and when nearly or wholly coked, is pushed to the back of the furnace. The object is to maintain a bed of incandescent carbon at the rear of the grate in passing over which the volatile from the green coal at the front will be burned. This method is particularly adapted to furnaces wherein gases pass horizontally over the fire. Before each firing the coked fuel is pushed back, leaving about one-third of the grate bare and all of the green fuel is fired on the bare grate. The fire door is cracked slightly to admit air for the volatile gases.

The spreading or alternate method of firing gives higher efficiency, higher CO_2, lower temperature of exit gases, and generates steam more uniformly than does the coking method, due to more uniformity in furnace temperature. The *Bureau of Mines* states that about the same amount of slicing and raking is required in either coking or spreading methods (of course excluding in this the leveling required in the coking method), but that the coking method of firing produces less clinker, since the leveling of the fire at the firing period shakes more ash through the grate, and lower CO_2, due to longer firing period, results, with a tendency to admit excess air through the thin spots. The analysis of ash shows no difference in the amount of combustible consumed for the two methods of firing. *Hays* says that the coking method is impossible with a fluctuating load. Holes that cannot be seen develop in the rear of the fuel bed. The coking method is a good smoke preventer, but experience is required before it can be used without loss of efficiency.

STANDARD PRACTICE FOR HAND FIRING

The following procedure in firing is recommended by the *Bureau of Mines:*

The fireman must take a proper position so that he can see the thin spots and can throw the coal onto them with the least effort. He should stand 4½ to 5 ft. in front of the furnace, and 12 to 18 in. to the left of the center line of the door. He should then be about 2 ft. from the coal, which is 6 or 7 ft. from the furnace front and preferably on a car.

The scoop should travel in a nearly straight line. At the end of the throw, the scoop should suddenly be stopped by laying it on the bottom edge of the door frame. The coal then flies off and is scattered over the proper spot. By thus stopping the scoop, the fireman saves effort, and locates the coal better. If he pushes the scoop way into the furnace, he has to jerk it back to get the coal off.
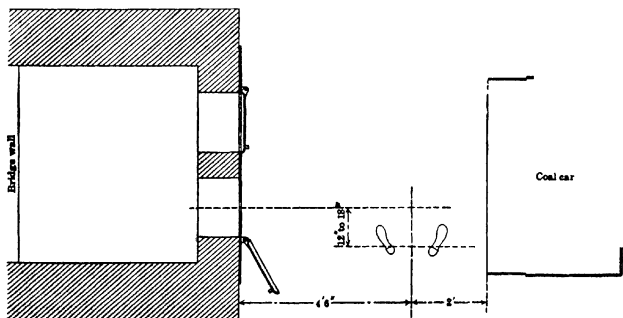
A PROPER POSITION FOR FIRING THE FURNACE
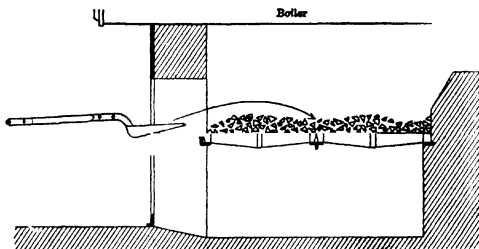
THE END OF THE THROW

The scoop is stopped by laying it on the lower edge of the fire door frame, and the coal, following the course of the arrow, slides off the scoop and falls on a thin spot in the fuel bed.

Hand firing is hard work, and requires considerable judgment and skill. There should be sufficient firing space for handling the shovel and tools.

If the coal is closer than 6 or 7 ft., the fireman is crowded and will stand away to one side of the door to avoid the intense heat. He cannot see the fire, and throws the coal in by guess. His scoop travels in the arc of a circle, scattering coal on the floor, and dumping it in a heap directly inside of the door. This results in an uneven fire, low efficiency, and requires raking of the coal onto the back part of the fire.
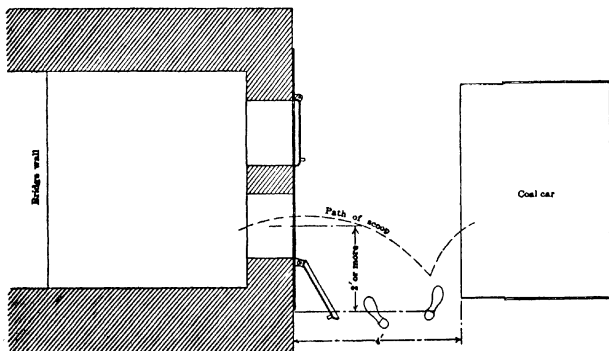
IMPROPER POSITION FOR FIRING

The fireman stands too near to the furnace and too far to one side. He cannot see the surface of the fuel bed and throws the coal in by guess; some of it falls off the scoop before the latter reaches the firing door. The coal car is too near the furnace. The dotted lines show the path of the scoop.

Provide a smooth firing floor, or a smooth bottom to the coal car, so that the shovel does not hit bumps and rivets. Such items delay the firing operation, keeping the door open longer than necessary and admitting an excess of air.

Hays says that about 1% of coal is lost in the average plant due to waste in handling at the plant. Coal is thrown on the floor and ground to dust by feet and wheels, and mixed with ash.

The *Bureau of Mines* recommends burning coal rapidly and at high temperatures in order to secure the best available economy. Fire small quantities of coal at short intervals, so that thin places do not burn through and admit large excess of air. The quantity depends on the grate size and draft. With a draft of 1 in. in the uptake, 2 to $2\frac{1}{2}$ lb. per square foot of grate is a good average. Thus, on a grate 6 by 8 ft., 100 to 125 lb. of coal, or about 6 to 9 shovelfuls, would be the quantity for one firing. The intervals should be about 5 min. For a higher draft, the periods could be 3 min., with a weaker draft they could be lengthened to 8 min., but under ordinary circumstances should never be more than 10 min. This method makes the coal supply more nearly proportional to the air supply, which in most hand-fired plants is nearly constant.

The following are reasons for light and frequent firing: When fresh coal is fired, the volatile matter is immediately distilled The process is nearly completed in 2 to 5 min., therefore immediately after firing large quantities of air should be admitted over the fire. After 2 to 5 min. it should be cut down

COAL CAR OF A GOOD DESIGN

Such regulation is practically impossible. As the air supply is practically constant, immediately after firing it becomes insufficient and incomplete combustion results. After most of the volatile matter has been driven off, the air is in excess. The two losses are much less when small amounts are fired at frequent intervals. Automatic air control devices can be purchased, but even with them frequent and light firing is best. Frequent firing alleviates the tendency to form a crust on top of the fuel bed.

A. Bement also calls attention to the importance of keeping a *hot* fire at all times, controlling the draft or number of boilers used by the load and the steam pressure. He states that any man can tell by sight if a fire is becoming cool, even without instruments, and that this is the surest standard to follow in hand-fired plants, just as the temperature of the fire is gauged in pottery work.

In looking for holes and thin places in the fire, be particular to look in the corners at the front of the furnace, and between the firing doors.

Where stokers are used, look to see if there are large air leaks through the coal hopper.

Firing doors are often opened too frequently while coal is not being fired in order to inspect the fire, and excess air is thus admitted. A 1½-in. mica-covered peephole in the door will avoid this. In one plant the CO_2 percentage was increased 1½% by this method.

As remarked by the *Bureau of Mines,* a skillful fireman can at a glance estimate the amount of coal required at a given spot. Almost unconsciously he picks the right amount, and selects the right mixture of fine and coarse coal. If the coal is burned way down, he selects coarse coal, to avoid its sifting through the grate. This also permits of the building up of the level on the spot more quickly, as the coal does not tend to fuse so much as slack. Thin and thick spots will occur, even with most careful firing. In places where the air flows freely, the coal burns faster, forming a thin spot. The cause of the variation in air flow may be the difference in the size of the coal, the accumulation of clinker or the fusing of coal into a hard crust. Before firing fresh coal, the fireman should note the thin places. They have bright, hot flames, while high spots have smoky flames or none at all. *Uehling* says to cover the holes, if burned through, with incandescent coal before firing Place the coal on the thin spots in thin layers. If deep hollows are filled at once, fresh coal may fuse and choke off the air, forming a new high spot. If high spots are missed for one or two firings, they will burn down to normal If the high spot is due to clinker, the clinker must be removed.

Burning Bituminous Coal.—The burning of bituminous slack coal is difficult, because it fuses into a hard, tight crust. This admits little air, and therefore the combustion rate is low. The heavier the firing, the worse is the condition. Some firemen fire heavy charges of 300 to 500 lb. They break the crust by lifting with the slice bar, and then level the fire. This is satisfactory with coals whose ash does not fuse readily For coals with a fusible ash the better method is to keep the fire about 5 in. thick, and fire small charges. The prongs of the rake can be used to break the crust if it does not burn through. The fire should be worked as little as possible, as the working of a fire is liable to cause clinker; furthermore, while the doors are open, excess air is admitted, and the fireman has more work.

A writer in *Power* recommends burning slack coal in small quantities and evenly spread, not over 5 to 8 in. thick. If the coal has a tendency to cake, slice frequently. Do not lift ash into hot zone. Simply run the slice bar under the fuel and twist slightly with a side movement to open up air holes. A shaking grate with 40% air space is satisfactory. Rock the grate, not violently, when the ash pit grows dark

Hays says · "Turn the hose on any fine coal-pile. It is impossible to burn some fine coals without wetting them. Fine coal tends to pack in the furnace, especially if dry, or if it contains much ash If it is wet, the steam generated will tend to loosen it. As a result, more coal will be burned, and that more uniformly, with less combustible in the ash, and less combustible carried over by the draft into the combustion chamber. There will be fewer cracks in the fuel bed, and the coal will burn with a great deal less excess of air."

Burning Anthracite.—Fire evenly, in small quantities, at frequent intervals, otherwise dead spots will appear in the fire. If the fire becomes

too irregular, burning in patches, nothing can be done but to clean the entire fire. After firing, the fire should be left alone, and the fire tools used as little as possible. Owing to difficulty in igniting, care must be taken in cleaning the fire. Intervals of cleaning depend on the coal and the rate of combustion. With small sizes and moderately high rates of combustion fires will have to be cleaned twice each eight-hour shift. As the fires become dirty, the depth of fuel may be 12 to 14 in.

According to the *U. S. Fuel Administration,* where steam-size anthracite is available at favorable prices, it can be used advantageously in conjunction with soft coal, even with equipment designed for the latter. Up to 20% of buckwheat or fine sizes of anthracite can generally be used without change. 20 to 40% anthracite screenings can be used with the soft coal by installing a turbine blower in the side wall of the ash pit, controlled by an automatic draft regulator of the "partial throw" type. This should operate on 3% of the steam generated, as will also a steam jet blower of good make. Larger quantities of hard coal can be used with buckwheat grates and forced draft, up to 70% for No. 1 buckwheat coal. Such grates have pin-holes or slots from $\frac{1}{8}$ up to $\frac{5}{16}$ in. width. Shaking and dumping grates permit cleaning without loss of pressure, and a large ash pit makes it unnecessary to open frequently the sealed doors used with forced draft. Comparatively large grate area must be used, 1 to 40 being the ratio of grate area to heating surface for No. 1 buckwheat, and 1 to 25 for No. 4. There should be $2\frac{1}{2}$ to 3 cu. ft. of combustion space per sq. ft. of grate area, and the fuel bed should be at least 6 ft. from the boiler tubes. The passes should become less and less in area so as to insure uniform velocity of the gases. Excess air must be kept down by the use of the uptake damper, and 15 to 16% CO_2 can be reached without danger of CO. Anthracite must be fired evenly in small quantities, with a bed not over 6 or 8 in., and the leveling bar used sparingly. Where an automatic regulator is used, the coal must be proportioned to the draft.

CLEANING FIRES

The tools recommended by the *Bureau of Mines* for handling the fires are illustrated and dimensioned on page 150, and the methods of using them are explained in the following paragraphs. The hoe and slice bar are used for cleaning the fire, and the rake for leveling the fuel bed.

Cleaning of the fire is necessitated by the fact that clinker and coarse ash will not pass through the grates. The intervals between cleanings depend upon the proportion of ash in the coal, the character of ash, and the type of the grate. If the coal contains much ash, or ash that is fusible, the fires have to be cleaned often; if light fires are carried, less clinker forms, and under such conditions the fire can often be run through a day shift without cleaning. The cleaning of the fires should be done thoroughly. All the clinker and ash should be removed, so that they cannot fuse to the side wall. They should be removed in such a way as to waste very little combustible. There are two methods of cleaning hand-fired furnaces.

In the side method one side of the fire is cleaned at a time. The good coal is scraped and pushed from one side to the other. The clinkers may have to be removed from the grates by the slice bar. When they have been

$2\frac{1}{2}$"

Welded

8'

1" Standard pipe

HOE

1" round bar
Welded to end of
pipe and blade
riveted to it

$2\frac{1}{2}$"

Welded   Welded

$2\frac{1}{2}$"

6'6   2'6

$1\frac{1}{4}$" Standard pipe

SLICE BAR

$2\frac{1}{2}$"

Welded   Welded

8'

1" Standard pipe

RAKE
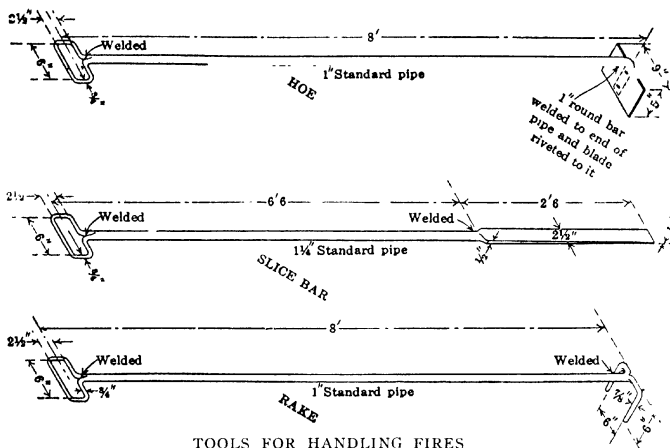
TOOLS FOR HANDLING FIRES

loosened and broken up, they are scraped out of the furnace with the hoe. The fireman should gather the clinker on the front part of the grate before pulling it out into the wheelbarrow, as this saves him from exposure to the heat. After the one side is cleaned, the burning coal from the other is moved and scraped to the clean side. It is spread evenly over the clean part of the grate, and a few shovelfuls of fresh coal are added, in order to have enough burning coal to cover the entire grate when the cleaning is done. This adding of coal is important, especially when the cleaning must be done with the load on the boiler. The clinkers are then removed from

SIDE METHOD OF CLEANING FIRE

A shows how the hoe is used to move the burning coal from the left-hand side of the grate to the right-hand side. *B* shows the use of the slice bar for the same purpose. The motion of the tools is indicated by the arrows

the second half of the grate. When cleaning is started, there should be so much burning coal in the furnace that enough will be left to start a hot fire quickly, when the cleaning is completed. If a light fire is carried, it may be necessary when starting to clean to put some fresh coal on the side to be cleaned last. During cleaning the damper should be partly closed.

A fireman, after becoming familiar with the side method, should be able to clean a 200 HP. boiler furnace in 10 to 12 min.

In the front to rear method of cleaning, the burning coal is pushed with the hoe against the bridge wall. It is usually preferable to clean one-half of the grate at a time. The clinker is loosened and pulled out of the furnace and the burning coal is spread evenly over the bare grates. If the front to rear method must be used while the load is on the boiler, the side method should be employed after the day's run is over, so as to prevent the large accumulation of thick and hard clinker at the bridge wall.

Some firemen have the habit of pulling the clinkers out of the furnace without scraping and pushing the burning coal against the bridge wall or to one side. This really is not a method of cleaning the fire   They run a slice bar under the clinker to lift it to the surface of the fuel. Then they take a hoe and pull the large pieces out   The small pieces are not easily detected and are left in the fire   These fuse in a few minutes, due to the high temperature near the surface of the fuel bed, and then run into the grates. Thus more masses of clinker are formed, which are usually worse than those previously removed. This habit should be discouraged.

In cleaning the fire in a plant running morning to noon, and noon to 5 30 P. M , break the clinker at 10 30 A. M., clean the fire at noon, again break the clinker at 4 P. M , and clean again after the day's shift is over. The cleaning of a banked fire should be done about two hours before steam is needed. It is advisable to bank the fire at the front of the grate near one of the doors. This exposes the clinkers, which can be pulled out.

THICKNESS OF FIRE

As stated by the *Bureau of Mines,* the thickness of the fire should vary according to the available draft.   (See section on Draft, page 198.) With 1 in draft available at the breeching, firing run of mine coal, a 4 to 8 in. fuel bed is best; the coarser the coal, the thicker the bed   A thick fuel bed offers more resistance than a thin one. Therefore, with the same available draft, there is less air passed through a thick fuel bed, which means a lower rate of combustion and lower capacity. If difficulty is experienced in maintaining steam pressure with a thick fuel bed, it may be possible to overcome the difficulty by carrying a thinner bed. The objection to a thin fuel bed is that too much air flows through without uniting with carbon, but a thin fuel bed *does not* pass oxygen through unburned unless there are holes in it. Evidence shows that from a fuel bed 3 to 4 in thick the gases rising from the surface average less than 2% oxygen, and about 25% combustible gas. As a result, considerable air must be admitted through the fire-doors and other openings to burn the combustible gases. A thick fuel bed does not necessarily decrease the free oxygen in the flue gas, but may actually increase it   Thickening the fuel bed increases the resistance to the passage of air through it   As the fuel bed is thickened, less air passes through, and less combustible gas rises from its surface. The higher draft, however, brings in more air over the fuel bed, resulting in a greater amount of free oxygen in the flue gases. Clinker has the same effect.

An experienced fireman says: "The greater the load, the thinner the fire. To burn a lot of coal you need a lot of air, and the only way you can get it through the fuel bed is to keep the fire thin." The difficulty of successfully burning bituminous coal increases with the volatile content. The percentage of volatile will affect the required depth of fuel bed.

The following suggestions by *Steam,* while not hard and fast, may be of service in hand firing bituminous coal, keeping in mind that sufficient draft must be available. Semi-bituminous coals, Pocahontas, New River, Clearfield, etc., require a 10 to 14 in. fire. Fresh coal should be fired at 10 to 20 min. intervals, and a sufficient amount charged for maintaining a uniform thickness of fuel bed. Pittsburgh bituminous coals require a 4 to 6 in. fire. Small charges should be fired frequently. Kentucky, Tennessee, Ohio and Illinois coals require a 4 to 6 in. fuel bed. Free-burning coals from Rock Springs, Wyoming, require an 8-in. fuel bed. The poorer grades, such as Montana, Utah and Washington coals, require about a 4-in. fuel bed. Anthracite buckwheat requires a fuel bed of 4 to 8 in.

From experiments of the *Bureau of Mines,* the following general statements as to relation of thickness of fuel bed to draft can be made: The rate of flow through a bed of constant thickness is approximately proportional to the square root of the pressure drop. As the thickness of the bed increases, the weight of air admitted decreases rapidly at first, then more and more slowly.

To put air at the same rate through double the thickness of bed requires twice the difference of pressure and twice the work on the fan. If the height of a cross-flow water-tube boiler is doubled, or if the length of the tubes of a parallel-flow boiler is doubled, and the thickness of the fuel bed is doubled, double the fan work will be required if the same weight of gas is to be carried through the boilers If two or three times the weight of gases is forced through a given fuel bed and boiler resistance to produce two or three times the capacity, the work expended by the fans will be 8 to 27 times as great.

The average coal requires for its combustion about 14 lb. of air per lb. of coal, of which about half, supplied through the fuel bed, has the effect of gasifying the coal, while the other half serves to burn the gas. Increasing the supply through the bed increases the rate of combustion, but, so long as there are no holes in the fire bed, does not affect the composition of the gases issuing from the fuel bed. The air required for the complete oxidation of the gases, in the visible flame, should be admitted directly *above* the bed, in small streams at high velocity. This air can be admitted through openings in the firing door, controlled by a rotary damper, and through cracks and leaks, and can be mixed with the gases by the aid of a steam jet. To admit such air through holes in the fire is wholly undesirable, because there is no way of judging or controlling the amount so admitted.

The effects of varying the thickness of the fuel bed have been analyzed by *A. P. Kratz* in tests conducted at the University of Illinois, on a B. & W. boiler fitted with a Green chain grate stoker, of Type K. The combustion chamber was unusually long, being formed by a tile roof on the lower row of boiler tubes. The first gas pass was at the back of the boiler, instead of at the front. The samples of the flue gas were taken from the combustion chamber just at the rear of the tile roof, at the point where the gases turn to go up to the first pass. This point was so close to the furnace that no air leaks chargeable to the boiler setting could occur, and yet so far away that the combustion was complete. These results probably indicate what can be expected from that type of furnace by varying the thickness of the fuel bed.

The adjoining curves show the relation between the thickness of the fire and the percentage of excess air, taking into account the load on the boiler. A 7-in. fire gives about the smallest percentage of excess air. It must be understood that the curves are only approximate, as a number of other factors besides thickness of fire affect the amount of excess air, such as draft conditions. At different loads the excess air decreases to a minimum and then rises as the thickness of the fire increases. With a thin fire, there is a tendency to the formation of air-holes. As the depth of the fuel bed is increased a greater draft is required, and there is a greater infiltration of air. The combined result of increasing the depth of the fuel above 7½-in. is an increase in the excess air. Inspection of the curve shows that

RELATION BETWEEN THICKNESS OF FIRE AND EXCESS AIR IN THE FURNACE—*Power.*

for a thin fire of constant depth, the excess air increases when the load or rate of combustion is increased, while for a thick fire of constant depth the reverse is true. When the load is made greater, a larger amount of air must be drawn through the fuel bed. In the case of a thin fire, holes burn through quickly with a heavy load. With a thick fire light loads would entail a very slow travel of the grate, with probability of burning through and admission of excess air at the back.

A study of the curves below shows that for each load there was a
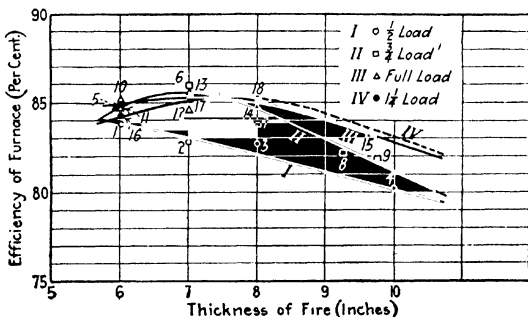
RELATION BETWEEN THICKNESS OF FIRE AND EFFICIENCY OF FURNACE—*Power.*

well-fixed thickness of fire that gave the best efficiency. As the load decreased this thickness became less. For 1¼ load the best fire was 8 to 8½ in. thick. For full load, the best fire was 7 to 7½-in. thick. For a ¾ load it was 6½ in. thick.

The effects of firing methods on combustion results are illustrated by the diagrams on page 155. The first four figures are modified from sketches by *W. C. Edge*. The second four figures are redrawn from *M. Gensch*. In every case the abscissae are time, and *A* represents the point of firing. In the first four figures the air line represents the relative amounts of air passing through the fuel bed; when the coal is fired the air supply through the fuel bed is immediately cut down and a crust quickly forms by fusion and further cuts down the air Then, as combustion of the solid part of the fuel proceeds, the fuel bed becomes more porous or holes may burn through, gradually increasing the relative amount of air through the fuel bed until the next firing. The carbon line represents the relative amount of carbon which is in the process of burning. After firing an appreciable time is taken for all of the coal to ignite. After the peaks of the carbon line are reached the amount of incandescent carbon decreases by combustion. When the air line is above the carbon line, excess air is entering the furnace; when the carbon line is above, there is insufficient air and the combustion is incomplete.

The first figure represents heavy firing at long intervals, with the dampers choked down The air supply is proper for much less than half the time. This is a common occurrence.

The second figure represents the same firing intervals as the first, but with the dampers wide open. This results in a little CO immediately after firing and large amounts of excess air for most of the time. This is also a common condition.

The third figure represents a better method than either the first or second; heavy firing at long intervals, but damper is opened wide soon after the firing periods and is closed down after part of the fuel has burned away.

The fourth figure represents the correct method of firing. Firing is light and frequent. The damper is set so that the load may be carried with the highest CO_2 and no CO.

Figures 1 to 4 apply where secondary air is supplied through holes in the fire. If the secondary air is supplied through dampers in the fire doors, this supply increases after firing, due to higher draft.

The 5th and 6th figures show the relative quantity of air actually required for different coals, with firing at fairly long intervals. The largest amount of air is required soon after firing, whereas (see figures 1 and 2) the air supplied at this time is the minimum.

See also pages 270 and 298.

In discussing hand firing *Kreisinger* points out the average soft coal requires about 14 lb. of air per lb. of coal, of which about half must be introduced above the fire, through cracks around the firing door and along the side walls and bridge wall, and through special openings, or through

1. HEAVY FIRING AT LONG INTER-
   VALS, DAMPERS CHOKED DOWN

2. HEAVY FIRING AT LONG INTER-
   VALS, DAMPERS OPEN

3. HEAVY FIRING, DAMPER REGU-
   LATED TO SUIT

4. METHOD OF CORRECT FIRING,
   LIGHT AND FREQUENT, DAMPER
   REGULATED

5. AIR REQUIRED FOR BURN-
   ING ANTHRACITE

6 AIR REQUIRED FOR BURN-
  ING HIGH VOLATILE COALS

7 AIR REQUIRED FOR BURN-
  ING HIGH VOLATILE COALS
  WITH FREQUENT FIRING

8 HEAT LIBERATED FOR USE
  OF THE BOILER UNDER THE
  FIRING METHODS OF FIGS.
  1 AND 2.

EFFECTS OF METHOD OF FIRING—*Natl. Engr.*

holes in the fuel bed. It is, however, difficult to maintain the proper ratio of secondary air, due to intermittent firing. Immediately after firing the fuel bed acts as a gas retort, giving off large quantities of volatiles, which are likely to escape in the form of smoke unless additional air is supplied for their combustion. At all times when there is a solid fuel bed, CO_2 from the lower layers of burning fixed carbon is reduced to CO by the upper layers, so that the fuel bed acts as a gas producer, requiring secondary air for the combustion of the CO, but not so much as during the period of volatile liberation. The right conditions can be approximated by varying the secondary air supply, as by automatic regulation or cracking the door after firing, or by extending the distillation process over the entire firing cycle. With heating boilers this can be accomplished by the coking method of firing, in which the coal is placed in large charges at the front part of the grate, and later spread over the grate and a new charge placed near the firing door. In power plants, the firing should be done on the two sides of the fire alternately, so that half the grate is distilling volatile matter all the time, the intervals between firing being cut down accordingly to only two minutes apart if necessary. Frequent firing has the further advantage of preventing the formation of large holes, which are
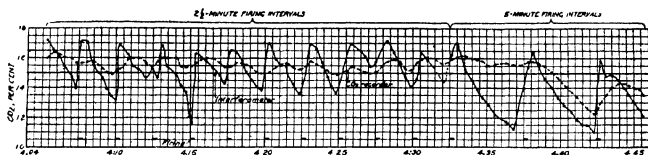
EFFECT OF FREQUENT FIRINGS ON FURNACE GAS

especially troublesome with Eastern coking coals. The chart given above shows the advantage of frequent firing, with Illinois soft coal. The heavy line indicates the record of an interferometer, which utilizes variations in refraction to give an instantaneous indication of the variations in CO_2, while the dotted line gives the record of a CO_2 recorder drawing samples from the same furnace, but subject to a 7-minute lag and a tendency to average the composition of the gas. Firing periods are indicated by small rectangles at the bottom. It will be noticed that the CO_2 percentage drops toward the end of each interval, and jumps during the firing period, but that the variation is much less marked with the short (2½-minute) firing intervals. In this test the secondary air, equal in amount to that coming through the fuel bed, was introduced through fourteen 1⅛-in. nozzles placed in the side walls and injecting the air in horizontal streams close to the surface of the fuel bed. The grate area was 30 sq. ft. and the rate of firing 22 lb. per sq. ft. of grate per hour. *Kreisinger* recommends that fuel beds be from 5 to 6 in. thick. Heavier beds require high draft, which causes inleakage of excess air. The draft damper should be so adjusted that the air supply through the fuel bed corresponds to the rate of firing. As the time for cleaning approaches, the draft should be increased on account of the thicker bed, but sudden changes should be avoided.

Coals with a high percentage of volatile cause greater fluctuations in the flue gas, as shown in the *Bureau of Mines* chart, Fig. C, p. 159, where the small rectangles every two to three minutes represent the firing periods. During the time of rapid distillation following firing, the entire air supply is utilized in burning the gases, and a high percentage of CO_2 results, probably accompanied by unconsumed CO, while a few minutes later, the air supply being constant, there is considerable excess air. By properly reducing the firing intervals, say to less than
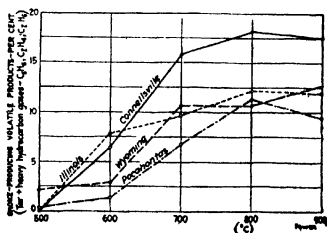
A. QUANTITIES OF SMOKE PRO-DUCING VOLATILE DISTILLED FROM SEVERAL COALS

two minutes, and alternating the sides of the grates, the cycles can be made to overlap, resulting in uniform flue gas conditions.

Tests by the *Bureau of Mines* show widely varying amounts of smoke-producing gases to be distilled from different coals, as illustrated in Chart A, page 156. At a furnace temperature of 1650° F. (900° C.) nearly twice as much gas is produced from the Connellsville coal as from the Pocahontas, and it is of a particularly troublesome composition

Samuel B. Flagg has prepared the diagrams in Figure B to interpret the results of tests on burning Pittsburgh slack at about 15 lb. per hr. per sq. ft. of grate. With the alternate spreading method of firing, one-half the grate was covered every five minutes, the assumed rate of distillation for each lot of coal being represented by the dotted lines, and the sum of the rates, or the resultant rate of the furnace as a whole, being shown by the solid line. The latter exceeded the

Rate of distillation from freshly charged coal

Rate of distillation from coal pushed back (Coking method only)

Rate of distillation Resultant curve

Area representing volatile distilled during smoke-producing period

Area representing volatile distilled after smoke-producing period

Critical Rate

B RATES OF DISTILLATION OF VOLATILE FOR ALTERNATE AND COKING FIRING —*Power*.

"critical rate" for 2 min. out of every 5, or 6 min out of 15, smoke being produced during such periods. 61% of the volatile is distilled at a rate above the critical. In firing every 15 min., using the coking method, the heaviest distillation occurs immediately after the partially coked coal is broken up and pushed back. Smoke is only produced during 2 min. out of 15, and its density is reduced by the fact that the fire-doors are open longer. 41% of the volatile is distilled at rates above the critical. In the settings tested, smoke was eliminated in many cases immediately after firing by admitting supplementary air through openings in the front of the furnace. It will be seen from the curves that the rate of distillation would be below the critical if it could be kept uniform. This can be controlled to some extent by keeping the furnace temperature down by exposing some of the boiler surface directly to radiation from the fire bed. The removal of the arch over the grate was found efficacious in this respect in the furnace under test. When the alternate spreading method is used, frequent firing tends to smooth out the curve, but there will be excess volatile at times, which can be taken care of by supplementary air and mixing by sudden changes in direction. With the coking method, the distillation can be better distributed over the firing period by the more rapid heating of the freshly charged coal, so that it will have less gas to give off when it is shoved back. This can be secured by reflecting some of the heat from the rear onto the green coal.

A. R. *Mumford* describes an investigation by the *Bureau of Mines* on a hand-fired plant containing an ordinary return tubular boiler 18 ft. long, 56 in. diameter, set 27 in. above grates, 6 ft. deep, 5 ft. wide. The bridge wall rose to within 5 in. of the shell, and the space behind it had been filled in so that the floor here was only 20 in. below the shell. The small combustion space and absence of provision for mixing gases made it necessary to burn pea anthracite except at night, when the load was lighter and the smoke from bituminous coal could not be seen. The grates could not be changed, but the depth of the combustion chamber behind the bridge wall was increased to 30 in. and semi-obstructing arches were built over the bridge wall and in the combustion chamber. 5 in. was cut off the bridge wall and the arch built over it extended back 3 ft. from the front of the bridge wall, providing hot firebrick surface for the ignition of any combustible mixture not already ignited, and reducing the gas passage under the boiler shell from 5.6 to 1.7 sq. ft. Just beyond the bridge wall the gas passage becomes 12 sq. ft., checking velocity of the gases and giving them more time to burn. The arch in the combustion chamber was of single-span construction, with only a semi-circular opening 4.15 sq. ft. in area next to the floor, causing the gases to turn down and undergo a second contraction, acceleration and expansion. The dampers had been left open, and fire controlled by ashpit doors and firedoors, causing stresses on the boiler and inleakage through the setting. With damper control and improved firing methods it was found that the fireman's average work per 1000 lb. steam was 1.94 min. with smokeless combustion of bituminous, as against 1.98 min. with the old method for bituminous and 2.69 min. with the old method for anthracite, with high ash and low heating value.

TIME SPENT BY FIREMEN IN VARIOUS OPERATIONS ON TEST BOILER

Test No.	Method	Fuel	Rate of Working Boiler, %	Time Spent on Firing, Min.	Time Spent on Cleaning, Min	Time Spent on Leveling Min.	Time Spent on Barring, Min.	Total Time Spent During 12-Hr. Test. Min.	Time Spent per 1,000 Lb. of Steam Produced, Min.
1	Old	An.	71	23.34	35.92	0	0	59.26	2.38
2	Old	An.	79	33.08	42.25	0	0	75.33	2.75
3	Old	An.	63	24.00	40.75	0	0	64.75	2.94
4	Old	Bit.	107	31.75	20.58	0	17.75	70.08	1.88
5	Old	Bit.	81	26.08	16.67	0	15.67	58.42	2.08
8	New	Bit.	125	25.50	12.67	24.51	17.75	80.43	1.87
9	New	Bit.	99	22.00	6.20	27.43	12.68	68.31	1.97
10	New	Bit.	85	18.05	6.33	31.73*	1.93	58.04	1.97

*Includes 3.50 min. for hooking.

In the improved method, at least as much time is spent on leveling as on firing and is used for covering holes and loosening the coke bed so that combustion takes place more evenly. On Test 10 the fires were barred only after cleaning, when the fuel bed consisted almost entirely of freshly-fired green fuel. Barring a fire generally produced objectionable smoke, but leveling from the top with a rake did not. Even with a rake smoke can be produced if forced too deeply into the bed. A safe method with regard to smoke abatement is to use the rake for breaking and leveling the top of the fire without disturbing that portion resting on the grates. The
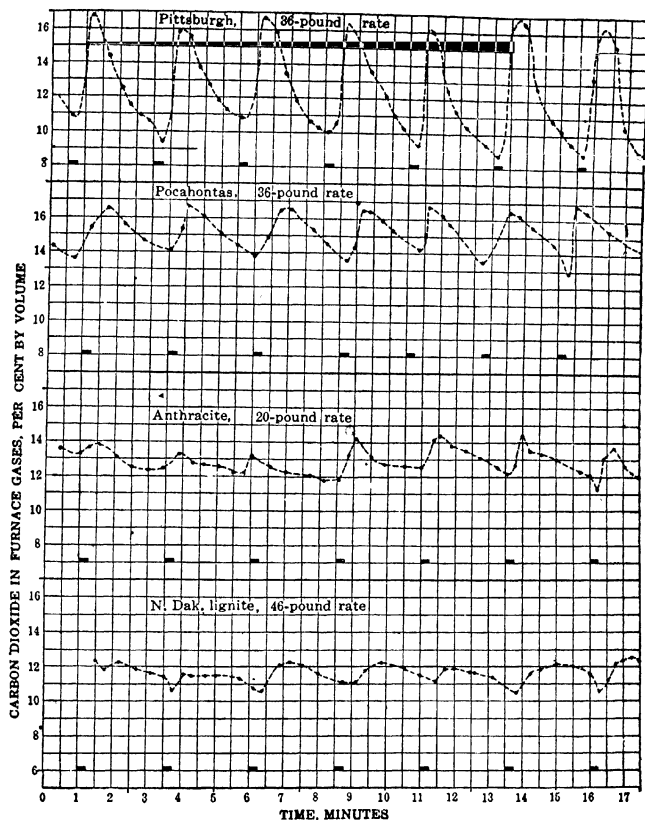
C. FLUCTUATIONS IN CO_2 THREE-MINUTE FIRING INTERVALS (p. 156.)

grates themselves should be kept free from ash obstruction by running a flat hook over them at intervals of four hours. This hooking of the fires does not disturb the fuel bed to any great extent, but does keep the air passages in the grate bars open. The improved firing method utilized the alternate system of firing. Thus only one-half of the grate surface is charged with green fuel at any one time, and the remaining half is left covered with a bed of freely burning incandescent coke from the preceding

firing. In this way the fluctuation in furnace temperature is reduced and a temperature high enough to ignite the mixture of combustible gases and air in the furnace is maintained. The procedure followed was to charge with fuel that portion of the fire reached through one of the firedoors and to break and level the other half as part of the same operation.

PERFORMANCE BEFORE AND AFTER MODIFICATIONS

	Before Modification						After		
Number of trial......	1	2	3	4	5	6	8	9	10
Kind of coal.........	An	An	An	Bit	Bit	Bit.	Bit	Bit.	Bit.
% of builder's rating..	71	79	63	107	81	56	125	99	85
Heat Balance per Lb. Coal As Rec'd									
Absorbed by water, %	57 9	55 7	58 9	66 0	61 0	59 0	66 5	65.7	69 0
Carried away by dry gases, %	18 9	18 4	20 1	22 1	24 0	27 7	19.0	18 5	17 4
Carried away by CO in dry gases, %.........	0 0	0 0	0 0	2 8	1 0	1 3	1 4	0 7	0 7
Carried away by steam in flue gases, %.....	2 8	2.3	2 3	3 7	3 6	3 5	3 5	3.5	3 5
Lost in ashpit refuse, %	14 4	16 2	14 7	2 4	4 8	2 6	3 1	5 3	4 1
Unaccounted for. %..	6 5	7 4	4 0	3.0	5 6	5 9	6 5	6 3	5 3
Evaporation per lb. coal, lb.	6.61	6 36	6 73	8.70	8 05	7.78	8 82	8 71	9 15
Coal per 1,000 lb. steam, lb.	151.3	157.2	148 6	114.9	124.2	128 5	113 4	114 8	109 3
Coal cost per 1.000 lb steam *........	$.694	.722	682	.378	.408	.422	.373	.377	.359

With the original anthracite firing it was found that steam could not be supplied in sufficient quantities if the fires were permitted to burn more than 4 hr. without cleaning, causing high ash-pit loss. The decrease in dry-gas loss with increase in rating also shows that with the damper left open the available draft was better utilized at full rating. The good efficiency at low rating, with the modified bituminous firing, is desirable, as the average operation is at 75% of rating. The decrease in dry-gas losses with decrease in rating (the reverse of the former trend) is brought about by decrease in pressure difference between the inside of the setting as the damper is closed, decreasing the influx of cold air through leaks in the setting. The average cost of fuel was reduced by the change, from $0.529 to $0.354 per 1000 lb. steam, based on 1922 prices of $6.58 per 2000-lb. ton for bituminous and $9.17 for pea-size anthracite.

J. F. Barkley discusses the method of hand-firing a down-draft Hawley furnace under a 155-HP. portable or locomotive boiler, using New River coal, nearly all fines with few lumps, with some slack coal from Pennsylvania, of a little higher volatile and ash. Such furnaces, properly operated, meet the smoke regulations of the District of Columbia. Volatile matter is meant to be distilled on the top grate, where also a part of the coke is burned; combustible gases are to be burned in the combustion space, a part of which lies between the two grates, while coke only is burned on the bottom grate. Air enters through the top firing doors and down through the top fuel bed, through the middle doors directly to the combustion space, and through the ash-pit doors and the bed of coke and ash; it is controlled by the various doors and the thickness of the fuel beds. It was found necessary to open the middle doors at time of firing to prevent formation of smoke at boiler overload, and the following practice was adopted: The top fire should be 6 in. thick after firing; let it burn down to about 4 in. Keep the bottom fire 3 in. thick. Before starting to fire

open the air dampers in the middle doors and open one middle door. Fire, not too quickly, over the entire top bed, covering the red coke. Level over the bottom fire. Shut the middle door. After about 1 min., depending upon how long a time the leveling of the bottom fire required, shut the air dampers in middle doors. When the top fire begins to cake over and the flame shorten, open the air dampers in the middle doors and break the fire straight up through with the poker, loosening up the entire fuel bed well. Then level. At this stage the boiler rating rises very rapidly. Shake the lower grates at long intervals, as shown by the conditions of lower fuel bed. No clinkers were found on either grate with this method. With the same furnace and coal but a different scheme of firing, the clinkers accumulated to such an extent in the top fire as well as the bottom, that the entire fire had to be cleaned every 8 hr., getting large masses of clinker. This was due largely to carrying a thick fire that gave a much lower boiler rating.

RESULTS OF HAND-FIRING MIXED FUEL

CO_2	O_2	CO	Boiler Rating	Efficiency	Remarks
11.90%	6 99%	0.36%	152%	74 5%	No attention to middle doors. Air dampers open in ash-pit doors.
11.50	7.80	0.30	157	73.0	No attention to middle doors. Bottom doors wide open.
11.53	7.73	0 00	148	76.1	Every attention given. Air dampers only open in bottom doors.
13.20	6.10	0 06	152	76 5	Every attention given. Bottom doors wide open.

The Suggested Rules for the Care of Power Boilers, proposed by the *A. S. M. E. Boiler Code Committee* in 1925, include the following:

Firing

C-17. Aside from the standpoint of economy, maintain the fire as uniformly as possible in order to avoid excessive combustion, undesirable variations in temperature, and possible gas explosions. In the event of flareback or the snapping out of burners, where oil or gas is used as fuel, shut off the fuel supply and thoroughly ventilate the boiler before resuming firing.

Cleaning Fires

C-18. Clean the fires when necessary, but preferably at stated periods and when boilers are operating at low rating, as at noon time and just before peak loads. Avoid holes in fire and excessive draft while burning out the fire. Clean fires as rapidly as possible to minimize cold air in the boiler. Do not fire too heavily immediately after cleaning. Do not pile hot ashes and clinkers against the boiler front; use care in quenching and remove ashes as soon as possible.

Banking Fires

C-19. When fires are banked and the furnace temperature is reduced, make sure that enough air is carried through the furnace and boiler to prevent the accumulation of combustible gases within the setting.

FURNACE GASES

The events in complete combustion of coal are analyzed by *Jos. Harrington* as follows: The coal, containing moisture, enters the furnace, where the moisture is first driven off. This is accomplished in a very short time, almost completely by the time the temperature of the coal reaches 212° F. As the temperature increases further, the volatile constituents come off. If the temperature at the point of liberation is high enough and oxygen is present, they burn in the space above the fuel bed, approximately as fast as they are distilled. The volatile constituents are not all driven off at the same temperature, so that this operation extends over an appreciable time. At about the time the volatile has all been driven off, the coal has reached a temperature sufficiently high to ignite the fixed carbon. The burning of the fixed carbon requires a considerable time, and a higher temperature than the burning of the volatile.

The three typical combustion conditions are: neutral, where the fuel is completely burned, but without excess of the oxidizing agent; reducing, where there is a deficient supply of the oxidizing or reducing element, as in the gas producer, blast furnace or within the fuel bed of a furnace; and oxidizing, where there is an excess of the element. Experiments of the *Bureau of Mines* prove that not over 50% of the air required for the complete combustion of coal can come through an incandescent fuel bed free from holes, and that the remainder must be introduced above the bed, unless it creeps in through unignited fuel or through holes in the fire.

When a fresh charge of bituminous coal is first spread over a hot fuel bed, the coal is heated up rapidly, and part of the combustible is distilled off shortly after the coal reaches the fuel bed. This distillation is a cooling process, and tends to hold the temperature down. The distilled volatile combustible is carried into the combustion space, where it is more or less completely burned, thereby raising the temperature.

Coal, when heated, begins to evolve gaseous and liquid matter at 475° F., the rate increasing up to 1000° F. In the distillation of bituminous coals, the reactions at temperatures below 1400° F. collectively absorb heat; those at higher temperatures evolve heat. The highest temperatures are not actually reached in an individual coal particle until its volatile is distilled off. The primary products are methane (CH_4), carbon dioxide (CO_2) and water, with the lower members of the paraffin series, naphthenes, and oxygenated hydrocarbons like cresylic acid. The hydrocarbons of low molecular weight, such as methane, ethane, etc., are easily burned to CO_2 and water vapor, but the heavier ones tend to "crack" and form substances hard to burn, such as soot. The modern theory is that, instead of there being a preferential combustion of either the hydrogen or the carbon, there is first an association of the hydrocarbon and oxygen, which may produce unstable compounds that decompose to form other substances and that oxidation and decomposition progress to complete combustion. Experiments by the *Bureau of Mines* with ordinary petroleum distillate in a cracking furnace showed that 41% of it decomposed on exposure for a minute to a temperature of 1650° F., and that the rate of carbon formation doubled once for every 90°. According to this reasoning, at 2725° F. all the hydrocarbons would be decomposed in .036 sec., and at 3275° F. in .0006 sec. Evidently the tar-forming hydrocarbons distilled from burning coal can live only a fraction of a second in a moderately rapid fire, and. in fast-burning, high-temperature fires they decompose

almost at the instant of formation. Probably the rate of decomposition is limited by the rate at which the heat of the hot gases can be transferred to the hydrocarbons.

The table below shows the volumetric composition in % of the furnace gases leaving the fuel bed for three minutes immediately after a firing, as given in a *Bureau of Mines* report covering a test on Collinsville, Ill, nut coal.

	CO_2	O_2	CO	C_nH_m	H_2	CH_4	Total Comb.
First Half Minute........	7.6	2 3	18 3	2	1.0	1.2	20.7
Second Half Minute	6.9	1.0	19 8	.3	3 6	1.4	25.1
Third Half Minute	4 7	.7	20.1	.4	{ 5.5	2.6	28 6
					{ 5.8	2.5	28.8
Fourth Half Minute	4 8	2 2	17 4	.4	{ 4.2	4 5	26.5
					{ 5.0	4.3	27.1
Fifth Half Minute......	5.9	1 4	19 1	2	7.6	3.0	29.9
Sixth Half Minute......	6 6	1.0	15 8	0	6.8	4.1	26.7

The hydrogen and methane are low immediately after firing, and gradually increase, while the illuminating hydrocarbons reach a maximum about two minutes after firing, and decrease to zero at the end of the third minute. The carbon monoxide remains high during the entire period of three minutes, while the percentage of carbon dioxide is comparatively low. The high CO is partly the product of distillation of volatile matter, and partly the result of decomposition of CO_2 In the lower layer of the fuel bed the carbon burns with oxygen to CO_2 As this passes through the upper layer of hot coke or coal, a molecule of CO_2 takes up an additional atom of carbon, and is reduced to two molecules of CO The percentage of CO formed when CO_2 is in contact with hot carbon depends upon the temperature of the carbon and CO_2, and to a certain measure on the length of time of contact The chart below shows the relations.
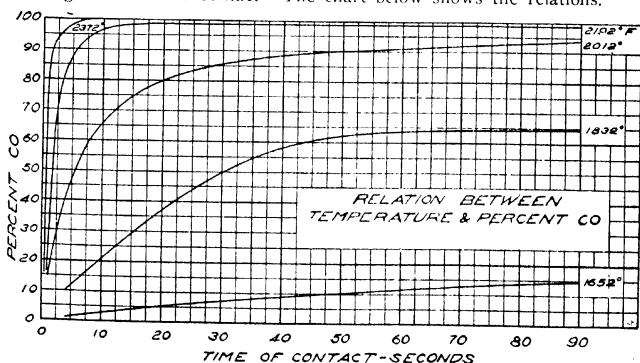
RELATION BETWEEN TIME OF CONTACT AND PER CENT. OF CO IN THE MIXTURE OF CO AND CO_2, WHEN CO_2 HAS BEEN PASSED THROUGH INCANDESCENT FUEL AT DIFFERENT TEMPERATURES
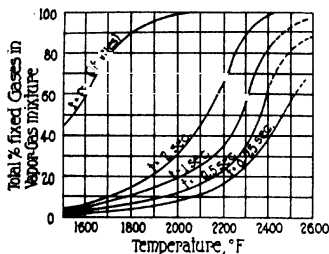
A. TOTAL GASES PRODUCED BY
   PASSING SUPERHEATED STEAM
   THROUGH HOT COKE.
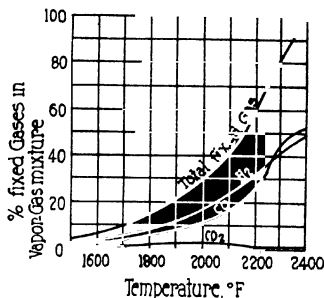
B. GASES PRODUCED BY 2 SEC.
   CONTACT.

Fig. A, by *J. K. Clement* and *L. H. Adams,* shows the result of passing superheated steam through an incandescent coke bed of about one foot thickness, maintained at the temperatures indicated. The values of "*t*" on the curves indicate the length of time for which the vapor stream is in contact with carbon (carbon depth divided by stream velocity), while the item "fixed gases" gives the total of CO_2, CO, H_2 and CH_4 in the issuing mixture of gases and water vapor. The amount of vapor decomposed into gases is seen to increase with temperature and with length of contact, the top line representing *Harries'* results for equilibrium condition, *i.e.* velocity approaching zero. Fig. B gives the composition of the issuing stream, for various temperatures and for 2 sec. contact (velocity ½ ft. per sec.). The combustible constituents increase rapidly until the temperature is about 2400° F., when the decomposition of the steam is practically complete. The CO_2 curve reaches a maximum at about 2000° F. Much more steam is decomposed in a short time at temperatures above 2200° F. than with longer contact at lower temperatures. The fuel beds of steam boiler furnaces average 2400° F., and if steam blown under the grates remained in contact with hot coal for 1 sec., the resulting mixture would contain 28% steam, 36% CO, and 35% H_2; for 2 sec., the mixture would contain only 4% steam, with 50% CO, 44% H_2, and 2% CO_2 and CH_4; while for 4 sec. practically all the steam would be decomposed. If insufficient air is supplied over the fire, the products of decomposition may pass out of the furnace unburned, especially as the oxygen from the steam is combined in the form of CO, and is not available for burning hydrogen. A similar loss from incomplete combustion may occur when fuels high in moisture are fired.

Fig. C, from charts by *Schulte,* gives the air and flue gas volumes as functions of total volatile of the ash-and-water-free coal and the % excess air. Each of the three pairs of curves radiating from the lower corner represents air consumed by the *volatile* in the pure coal, also the flue gas produced therefrom, when using zero, 25% or 75% excess air. Of the upper curves, each of the five sets refers to a stated amount of excess air—zero, 25, 50, 75 or 100%. In each set the straight line represents the

Y-axis: AIR & GASES CU. FT. PER LB. (0, 100, 200, 300)
X-axis: VOLATILE CONTENT % (0, 10, 20, 30, 40, 50, 60, 70)

COKE AN. LEAN RICH GAS G.F LIGNITE PEAT
OLD COALS   YOUNG COALS
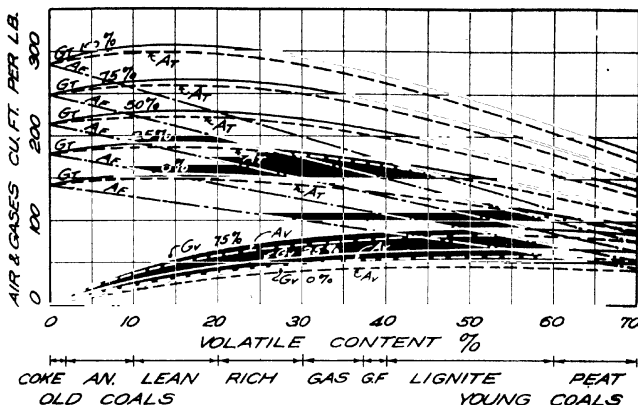
C. FLUE GASES DEVELOPED PER LB PURE COAL

G_t = total gases, A_t = total air, A_t = air for, and gases from, fixed carbon, G_v = gases from volatile, A_v = air for volatile, A_n = anthracite, G.F = gas flaming coals.

air consumed by the *fixed carbon* in the fuel (and therefore also the equal volume of flue gas produced from it), the lower curve the *total air* supplied to the given fuel, and the upper one the *total flue gas* produced. The curves for air and gases for volatile diverge as the gas content of the coal increases, while the curves for the fixed carbon behave in the opposite way. Since this latter effect is stronger than the former, the curves of total air and total flue gases are wider apart with lean coals than gas coals, so that an extremely great excess of air produces worse results from the point of view of firing in the case of the lean coals. The reason for this is the great demand for air on the part of the free hydrogen, which results in flue gases having a high burden of nitrogen, whereas the hydrogen already combined with oxygen produces only water vapor without nitrogen and without heating value. Fig. D shows, as in a solid model, the air and gas quantities, at 25% excess air, as influenced by the ash and water content of the coal. As the latter increases, the lines become flatter and flatter, and are practically straight at 70% ash and water. The curves lying toward the region of gas coals are somewhat inclined, but the equalizing effect of the ash and water content is clearly noticeable.

Schulte states that the combustion of the volatile constituents is closely limited as to time by the interval they remain floating previous to contact with the heating surface, and lasts as a rule only a few seconds. As far as the coke residue is concerned, the time element varies widely, depending on the velocity of the draft and the length and rate of travel of the grate, and may last from ½ to 1½ hr. It is an advantage for the coke residue to have air rich in oxygen, but it is a disadvantage not to have the air
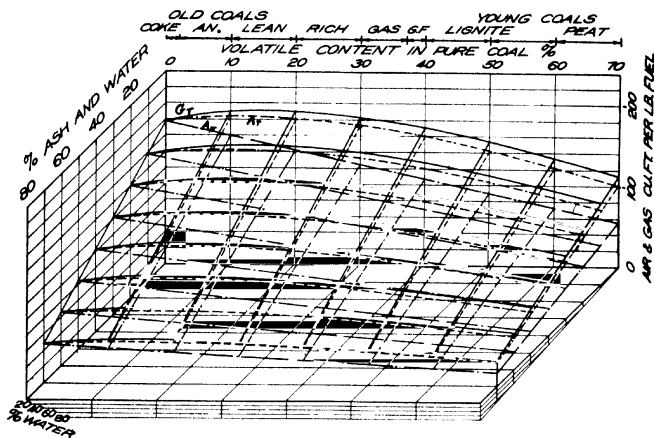
D. FLUE GASES FORMED FROM COAL AS FIRED, WITH 25% EXCESS AIR

Gt = total gases, At = total air, Af = air for fixed carbon.

preheated. The volatile constituents get air that is heated, but more or less deprived of its oxygen.

It is impossible to achieve in the combustion chamber a good mixture of the gas with the air. It is true that the air enters in a state of fine subdivision, because of its passage through the numberless interstices of the bed of fuel on the grate. On the other hand, it enters from one side only, and since it is heavier than the gases and since both of them fall immediately under the influence of the chimney draft, there is always present the danger of stratification within the combustion chamber in accordance with the respective specific weights. In chemical processes special constructions are employed to counteract these tendencies, but for certain reasons it is not feasible to use them in furnaces. It might be possible, however, to employ in burning coal on a grate methods similar to those used in pulverized-coal firing, namely, to produce in the combustion chamber the desired turbulence and thorough mixing by air injection. Actually, however, it is possible to employ this only to a limited extent, because as the air is introduced into the furnace from above, the draft from below is reduced to the same extent, and as a result of it the velocity of combustion of the coal on the grate is correspondingly delayed. Because of this, air admission to the upper part of the firing chamber is used in connection with traveling grates and stokers only under exceptional conditions. This may be done in the first place with fuels very rich in gas, such, moreover, as are burned with a deep layer of coal, so that under certain conditions CO formation takes place in the fuel bed, which produces an increase in the amount of combustible gases available. This occurs, for example, with the Vesuvio grate. In order to obviate the harmful

influence of the reduction of the flow of air from under the grate, one might, in the case of traveling grates, shut off the draft in the first section of the grate, i.e., the zone of gasification. Here the draft actually hinders the ignition of the coke residue. Instead of this the same amount of air, preheated as highly as possible, may be blown on to the grate from above. If this is done the blast will produce a powerful turbulence in the gases and will materially accelerate their combustion, this action being increased still more on account of the preheating of the air of combustion. Up to a certain point the shape of the roof may assist the mixing; this will occur if the roof is given a backward sweep so as to compress the gases. This can be used, however, only with lean and low-grade fuels.
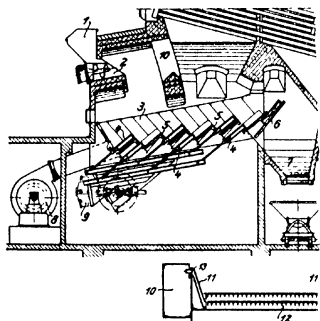
VESUVIO GRATE
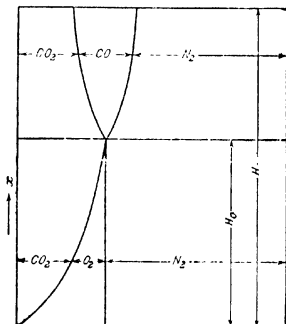
1 VERTICAL VARIATION OF GAS PASSING THROUGH FUEL BED.

Wilhelm Nusselt gives, in Fig. 1, the composition of the gases ascending through a coal bed fed by a throwing stoker, vertical distances representing distance above the grate bars. In the lower part, O_2 from the air unites with carbon according to the relation

$C + O_2 = CO_2 + h$, where $h = 14{,}648\ BTU$ per lb. C burned, at 59° F.

until the height H_0 is reached, where the 21% O_2 in the air is exhausted. The CO_2 occupies the same volume as the O_2 forming it, hence N_2 remains constant at 79%. Above H_0, the reaction is

$C + CO_2 = 2CO - h$, where $h = 5738\ BTU$ per lb. solid C burned, at 59° F.

The CO occupies twice the volume of the CO_2 producing it, and the % N_2 in the mixture decreases. The remainder of the study is based on the idea of vertical columns of air and coal, and in Figs. 2 to 4 the distance AB can be considered as the horizontal distance between the two nearby coal particles, at a given height from the grate. Even in the lower or combustion zone, the affinity of O_2 for coal is so great at fuel-bed temperatures that at the coal surfaces A and B the O_2 concentration becomes zero and the CO_2 21%, while out in the passage the O_2 and CO_2 add to

2. Combustion Zone   3 Gasification Zone   4. Intermediate Zone
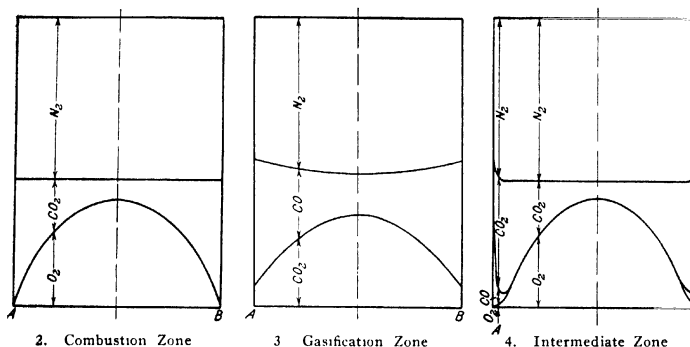
HORIZONTAL VARIATION OF GAS IN SPACE BETWEEN TWO COAL
PARTICLES AT SAME LEVEL

21%, Fig. 2. Continued combustion at points on the surface depends on
the rate at which oxygen can reach them, that is, the rate of diffusion of
CO_2 and O_2, which is a purely physical phenomenon. This is greatest in
the lower zones, where the main gas current is richest in O_2, hence the most
coal is burned there, and the action becomes less intense until the level is
reached where the O_2 is exhausted. Above it, part of the CO_2 in contact
with coal is broken down to CO, and gasification of the fuel occurs, form-
ing a combustible gas. The equilibrium proportions of CO_2 and CO in the
gas in immediate contact with the coal depend on the temperature; the
gasification continues at a rate dependent on the rate of diffusion of CO
from the coal surface and of CO_2 from the gas stream to the coal surface.
As the reaction involves a doubling of the gas volume, the coal surface
acts as a "source," the analysis in the space between two nearby coal
particles in the gasification zone being as in Fig. 3. The division between
the combustion and gasification zones is not sharply defined, and the thin
layer of CO in contact with a piece of coal near the boundary diffuses into
the products of combustion and burns with the O_2 diffusing out of the
gas stream, the gas composition across the small space being as in Fig. 4.
In the production of Dowson gas (Mischgas), a mixture of steam and air
is blown under the grate, and *Nusselt* states that the changes are chemical
only on the coal surface, and by diffusion elsewhere. No CO and H_2 are
produced in the combustion zone, as their affinity for O_2 is so great that
they would be instantly burned, hence the steam and N_2 content remain
constant, and the CO_2 diffuses from the coal surface to the interior of the
small gas passages, the condition resembling that shown in Fig. 2. In the
upper or gasification zone, where steam, CO_2 and N_2 are present, but no
O_2, the following reactions proceed at the surface of the coal:

$C + CO_2 = 2CO - h$, where $h = 5738\ BTU$ per lb. solid C burned, at 59° F.
$C + H_2O = CO + H_2 - h$, where $h = 4190\ BTU$ per lb. solid C burned,
at 59° F.
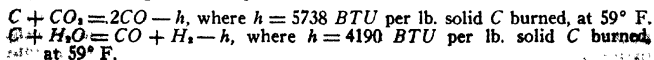
Subtraction gives the water-gas equation

$$CO_2 + H_2 = CO + H_2O - 1548 \ BTU \ \text{per lb. } C \text{ in the } CO_2$$
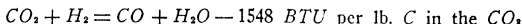
as often cited, but the author claims that instead of this the *two* reactions take place on the glowing coal surface, and that the CO and H_2 formed diffuse outward into the passing gas, while the CO_2 and H_2O work inward and gasify the coal, the rate of gasification depending on the rate of diffusion.
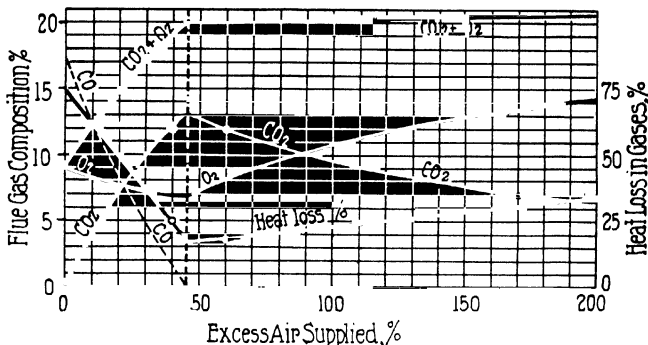
E   FLUE GAS COMPOSITION AND HEAT LOSS WITH VARYING EXCESS
AIR

D. Haarmann has calculated and plotted in the above Fig. E the composition of flue gases from the combustion of coal of the following analysis: *C* 80%, *H* 4%, *S* 1%, *O* 9%, *N* 1%, moisture 4%. The most desirable condition is with 45% excess air; CO_2 alone is not a safe criterion. 12% CO_2 may be secured with 40% excess air, involving 1.6% CO and 25% loss in the gases, or with 60% excess air, no CO and 18% loss. The flue gas loss as calculated is based on 626° F. stack gases and 68° F. air, and includes any loss due to incombustible gases. It is seen to run high when too little air is used, and emphasizes the importance of frequent determination of the $CO_2 + O_2$, which should always be above 20%.

Tests made by the *Bureau of Mines* on an experimental hand-fired furnace showed that the fuel bed acts very much as a gas producer, the combustible gases being consumed in the space above the fuel bed. Fig. F is typical of analyses of gas from different points in the fuel bed.

It will be noticed that CO_2 reaches its maximum in the lower part of the bed, while the distillation of combustible gases (CO, H_2 and C_nH_m) proceeds until they form 30% of the gases near the top, and 26% as they issue from the fuel bed. The thinner fuel beds (say to 6 in.) are sufficient to produce the maximum of CO_2, which decreases in passing through a thicker bed. The composition of the issuing gases seems to be independent of the air supply through the bed, which only influences the rate of com-
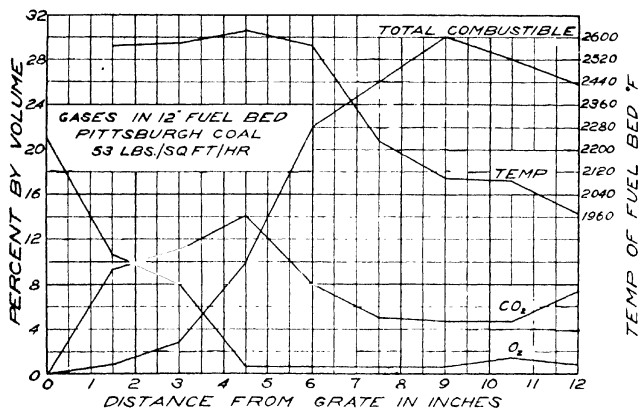
F. COMPOSITION OF THE GASES AND TEMPERATURES AT DIFFERENT
   DEPTHS OF A FUEL BED 12 IN. THICK OF PITTSBURGH COAL
   BURNED AT THE RATE OF 53 LB. PER SQ. FT. PER HR. IN A SMALL
   HAND-FIRED EXPERIMENTAL FURNACE.

bustion of coal; that is, 1 lb. of coal is gasified for each 7 lb. of air passed
through the bed, and the air for complete combustion of the CO, etc.,
must be supplied as secondary air.

The fuel bed changes the solid fuel to gas, to which additional air
must be supplied and the mixture burned in the combustion space. These
facts prove the importance of spacious combustion chambers. For this
reason some provision to supply air above the fuel bed is made in most
commercial appliances designed to burn soft coal. Furnaces for soft coal
generally have large combustion spaces.

The following table gives a summary of the series of tests:

AMOUNT OF COMBUSTIBLE IN GASES ISSUING FROM FUEL BED AT
DIFFERENT RATES OF COMBUSTION

	6-in. Fuel Bed		12-in. Fuel Bed	
Pittsburgh bituminous	20-124 lb.	19-30% (one 11%)	20-185 lb.	15-30%
Anthracite	20-100 lb.	18-27%	20-100 lb.	21-32%
	3- 10 lb.	6-24%	3- 10 lb.	4-22%
Coke	20-106 lb.	11-18%	20-118 lb.	22-24%
	3- 10 lb.	3-13%	3- 10 lb.	6-13%

Ralph A. Sherman and *S. P. Kinney* have plotted these tests in the
accompanying Fig. G. In the upper half the descending curves represent
the oxygen content of the gases passing through various beds of fuel,

Distance from Grate, In.
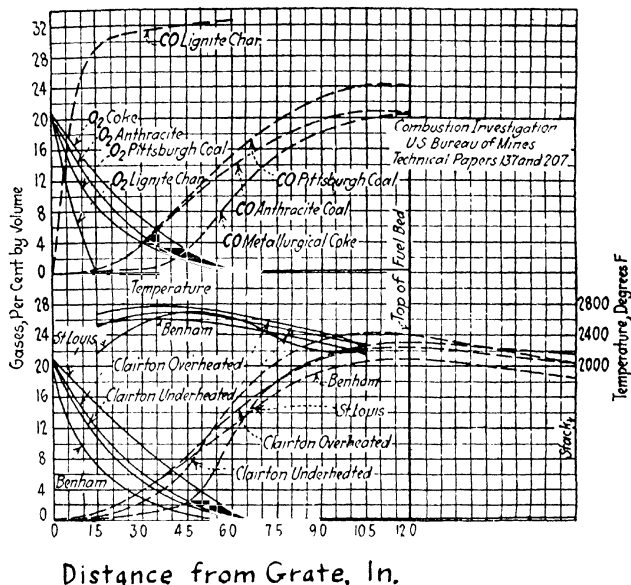
G. MEAN GAS COMPOSITION AND TEMPERATURES IN FUEL BEDS OF
DIFFERENT MATERIALS —*Iron Age*

including a metallurgical coke, anthracite coal, Pittsburgh bituminous and
lignite char, while those in the lower half represent the same for samples
of Benham, St. Louis and Clairton coke. The ascending curves in both
parts represent CO content. The combustibilities of the cokes are some-
what different in the lower part of the fuel bed, as indicated by the rate
of decrease of the oxygen, and are quite similar at about 6 in. above the
grate, but again are different near the top of the fuel bed, as indicated
by the CO. The Benham coke reduces the O_2 content of the blast more
rapidly than do the other cokes in the first few inches, but, higher in the
fuel bed, reduces the CO_2 to CO less rapidly than do the other cokes. The
Pittsburgh and anthracite coals are more combustible than coke and the
lignite char is highly combustible.

Fig. H, page 172, also illustrates graphically the general process
of combustion in and beyond the fuel bed, the three zones in the fuel bed,
the gradual consumption of the combustible gases, and re-formation of
CO_2, in a properly proportioned combustion chamber.
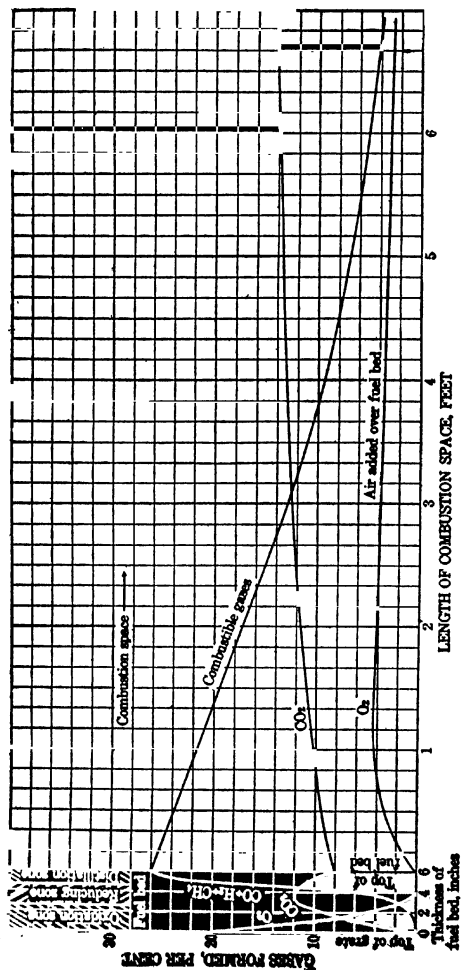
H. COMPOSITION OF GASES IN THE FUEL BED AND IN THE COMBUSTION SPACE

The gases at the top of the fuel bed contain no free oxygen and a high percentage of combustible gases, which burn in the space beyond the fuel bed after oxygen has been admitted. This diagram is a generalization of the results of many tests.

The table below, giving results of tests by the *Bureau of Mines* upon a hand-fired furnace fitted with a gas-mixing arch, shows that the combustible gas is nearly completely burned by the time the gases reach the rear of the combustion chamber. The gases can easily be burned. It. is the tar vapor and the small solid particles of floating carbon that present the difficulty in the combustion of soft coal.

ANALYSES OF GASES IN HEINE BOILER SETTING WITH PLAIN GRATES, 62 CU FT COMBUSTION SPACE PER SQ FT GRATE, AND GAS MIXING ARCH, BURNING TENNESSEE COAL

	Time	CO_2	O_2	CO	H_2	CH_4	C_nH_m
Test No. 364, 21 90 lb of dry coal per sq. ft grate per hr.							
Top of fuel bed	12 30	5 7	0	20 3	6 0	2.7	0
Rear of comb cham.	12 30	12 6	5 6	0	..	..	..
Test No. 367, 26 41 lb. of dry coal per sq ft grate per hr							
Top of fuel bed... . . . (*a*)	7.30	4 4	7.4	9.5	1.2	2 4	.8
Rear of comb. cham. .... ..(*b*)	7.30	13 3	0	.9	..	..	..
(*a*)	9 30	5 4	0	23.6	7.8	1.2	.2
(*b*)	9.30	15.5	.6	.7	.	..	..
(*a*)	11 30	5.2	2	23.8	5.4	1.8	0
(*b*)	11 30	14.6	.2	1 0	..	..	..

The effect of increasing the volume of the combustion space is shown by a series of tests conducted by the *Bureau of Mines* at Pittsburgh. The
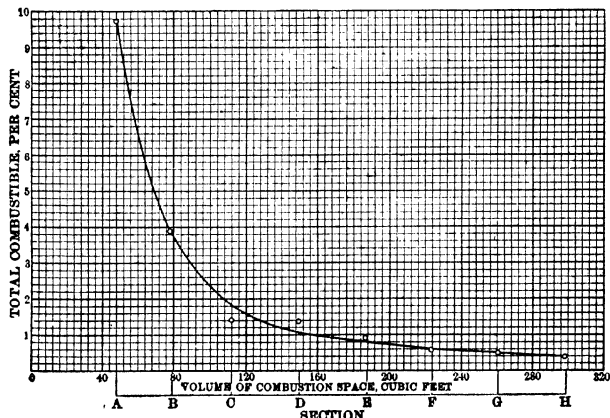
J. COMBUSTIBLE CONTENT OF FURNACE GAS WITH AN AVERAGE RATE OF FIRING OF 65.4 LB. OF COAL PER SQ. FT. PER HR. ON A MURPHY STOKER

larger the combustion space the more effective is the mixing, and therefore the combustion is more complete and smoke is less likely to be found. Fig. J shows the completeness of combustion at different points in a large combustion chamber. At a point where the gases from a Murphy Stoker of 25 sq. ft. projected grate area had passed through 160 cu. ft., there was 1% of combustible in the gases. After they had traversed 250 cu. ft. there was ½% of combustible in the gases.

COMBUSTION SPACE IN TYPICAL ACTUAL BOILER SETTINGS

Type	Torpedo boat	Loco-motive	200 HP. Heine	B. & W.	
Grate surface, sq. ft.	58.6	30	35	87.4	
Combustion space, cu. ft.	136	160	250	318	
Same, with 12-in. fire	78	130	215	230.6	
Ratio comb. space to grate area	2 34	5.34	7.14	3.64	
Same, with 12-in. fire	1.33	4.33	6.14	2.65	
Rate of combustion, lb. coal per sq. ft. grate surface	40	60	25	42.0	13.0
Sec. each cu. ft. stays in comb. space	0.077	0.17	0.58	0.15	0.49
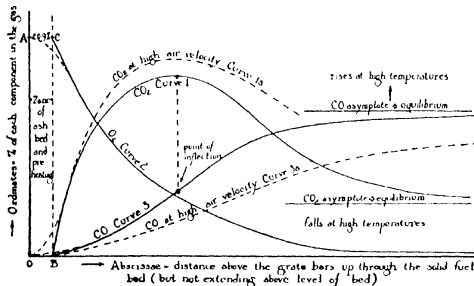
K. COMPOSITION OF GASES PASSING THROUGH A COKE-FIRED FUEL BED—*Ind. and Engg. Chemistry*

The accompanying Fig. K, by *W. K. Lewis*, gives a generalization of the work of the *Bureau of Mines* on the composition of gases at various depths in coke-fired fuel beds, at high and low air velocities. For low-ash fuel the bottom of the bed corresponds to the line BC, and the CO_2 curve rises rapidly at the start, at a rate which is practically independent of the velocity of the air up through the bed. The O_2 decreases by a logarithmic curve, the rate of disappearance being proportional to the amount present. The CO is formed from reduction of CO_2, and the rate of formation is proportional to the CO_2 present, shown by the fact that the slope is zero at the start and increases until the CO_2 is at a maximum, after which the CO slope, while still remaining positive, decreases as the curve approaches a horizontal asymptote. Were the bed indefinitely thick, the CO_2 and CO curves would approach equilibrium states, the asymptotic lines representing them being further apart the higher the air velocity and temperature. The left-hand strip in the diagram represents for a high-ash

fuel the lower zone, containing little combustible matter, where pre-heating of the air is the principal phenomenon, the characteristic reactions beginning at BC. The rate of formation of CO_2 is proportional to the rate of diffusion of oxygen through the incombustible gas film surrounding each incandescent carbon particle, hence to the air velocity. Increase in air supply and in CO_2 produced go together, hence the composition of gases is not much changed with increase in rate of heat production. The radiation to a heat-absorbing body "in sight" of the bed, such as a boiler, is proportional to the fourth power of the absolute temperature, hence the temperature of the bed will rise only slightly to dissipate the additional heat corresponding to increased combustion rate, and the temperature in such a furnace is not subject to great variation. Low-grade fuels require a temperature of say 1650° F. to maintain combustion, hence the cooling effects of radiation must be avoided by the use of Dutch-oven construction with heat-reflecting insulated walls. Hydrocarbons distilled from coal in the absence of oxygen "crack" when heated, producing carbon particles or smoke, but if the coal is heated in the presence of oxygen at temperatures below their ignition point, the hydrocarbons do not release carbon, even if later decomposed in the absence of oxygen. For this reason fresh coal should not be thrown on top of the fuel bed from which oxygen-free gas is issuing, but should be placed on a cleared area obtained by pushing back the hot coke from the fire door. The heating and distillation of fresh coal in the presence of air accounts for the ability of chain grates and inclined stokers to maintain high combustion rates without production of smoke. The presence of CO, unaccompanied by oxygen to burn it, in gases issuing from any fuel bed over 3 or 4 in. thick, shows the necessity of secondary air being introduced which cannot possibly come through the fuel bed.
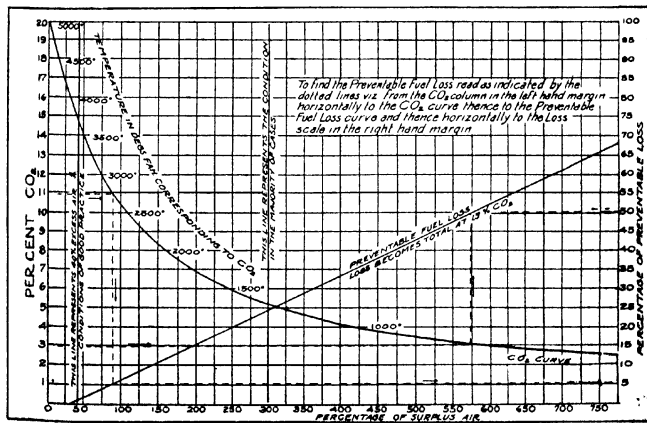
A. RELATIONS BETWEEN CO_2, THEORETICAL FURNACE TEMPERATURE, EXCESS AIR AND FUEL LOSS

FURNACE TEMPERATURE

Fig. A, by *J. W. Hays,* showing the temperature of the gases of combustion for various percentages of CO_2, is based on the assumption that all heat developed goes to raising the gas temperature. This chart also shows the relation between percentage CO_2 in the flue gas and amount of excess air. Reducing excess air results in higher furnace temperature, which may give a higher flue gas temperature. Building up the CO_2 percentage may appear to increase the heat loss up the stack if temperature alone is considered, but the actual quantity of heat lost is decreased, for the quantity of gases has been decreased. Fig. B, by *H. G. Hays,* gives furnace temperature as a function of air supply.
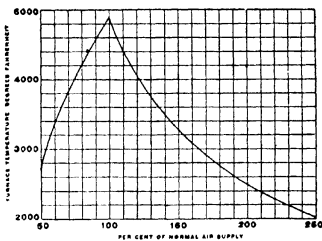
B   AIR SUPPLY AND COMBUSTION
        TEMPERATURE—*Factory*

Combustion takes place more rapidly at higher temperatures, and is more nearly completed in the furnace. The *Bureau of Mines* says that so long as combustible gases are kept sufficiently hot to allow of their combustion, the advantages to be gained by a further elevation of temperature are partly, if not entirely, offset by resulting disadvantages. In one case, the arch was removed to allow direct radiation from the fuel bed to the shell, and the lower furnace temperature resulted in less clinker formation. It also gave a slower distillation of the volatile gases, with better smoke consumption.

The charts on p. 177, adapted from *D'Amour,* can be used to determine the maximum possible furnace temperature from the ultimate analysis of the coal and the analysis of the furnace gases; if the furnace gas analysis is not available, it can be assumed the same as the flue gas. Fig. *A* shows the total thermal capacities of the principal gases in BTU per pound of gas at various temperatures, thus taking into account variations of specific heat with temperature.

The method of using this chart is best explained by a practical example. Assume, as a furnace gas analysis (volumetric), $CO_2 = 11\%$, $O_2 = 0.3\%$, $CO = 0.2\%$, $N_2 = 88.5\%$, obtained by burning a coal of the following analysis:

Carbon	82.88%
Hydrogen	4.13%
Oxygen	2.61%
Nitrogen	1.38%
Sulphur	1.51%
Ash	7.49%
Heat value	14,659 BTU per lb.

A furnace temperature curve is plotted as follows for the composite flue gases resulting from the combustion of a pound of the given coal. The proportion by volume multiplied by the molecular weight of each constituent gas gives its relative weight. The relative weight divided by the
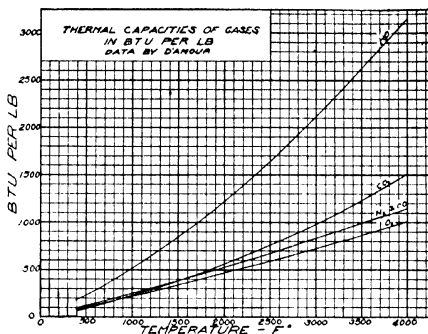
FIG. A. THERMAL CAPACITIES OF FLUE GAS CONSTITUENTS
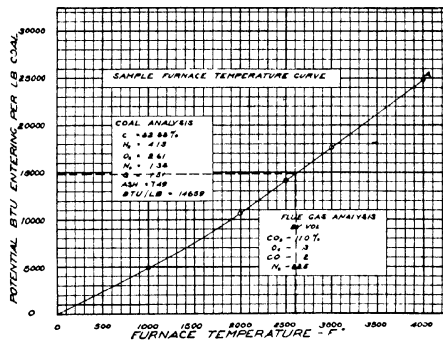
FIG B HEAT CAPACITY CURVE FOR EXAMPLE GIVEN

sum of all the relative weights is the proportion by weight, as shown in the following table:

Gas	% by volume	Mol. Wt.	Rel Wt.	% by Wt.
CO_2	11.0	$12 + (2 \times 16) = 44$	4.84	16.25
O_2	.3	$2 \times 16 = 32$	.096	.32
CO	.2	$12 + 16 = 28$	.056	.19
N_2	88.5	$2 \times 14 = 28$	24.78	83.24
	100.0		29.772	100.00

The weight of gases per pound of coal is found as follows:

$$\text{Lb. air supplied per lb. coal} = 3.036P \left(\frac{N_2}{CO_2 + CO} \right)$$

$P =$ carbon burned, stated as proportion of the coal,
$\quad =$ proportion of carbon in coal minus carbon in ash.
$N_2 =$ proportion by volume of nitrogen in the flue gases.

Assume 5% of coal went into ash-pit, and that 25% of the refuse was carbon. Then $.05 \times .25 = 1.25\%$ of coal is carbon in ash.
$P = .8288 - .0125 = .8163$.

$$\text{Lb. air per lb. coal} = 3.036 \times .8163 \left(\frac{.885}{.112} \right) = 19.57$$

95% of the coal was consumed, and is therefore present in gases.
Lb. of gas per lb. of coal $= 19.57 + .95 = 20.52$ lb.

The total heat of the gases of combustion per pound of coal, at 4000° F., say, is then found as follows:

Gas	Proportion by Wt.	Thermal Capacity at 4000° F., from Fig A	Total thermal capacities
CO_2	.1625	1515	246.18
O_2	.0032	1010	3.23
CO	.0019	1150	2.07
N_2	.8324	1150	957.95

Total thermal capacity per lb. gas $= 1209.43\ BTU$

Total heat in gases per lb. of coal $= 20.52 \times 1209.43 = 24,817\ BTU$, which is point A in Fig. B. The heat capacities of the gases of combustion at 3000, 2500, 2000 and 1000° F. are calculated similarly and the complete curve plotted.

The heat entering the furnace per pound of coal actually burned comprises the heat value of the coal, plus the sensible heat in the air used to burn a pound of coal. Assume the air temperature as 70° F.

Heat in air $= 19.57 \times (70 - 32) \times 0.24$ (24 is the specific heat of air at ordinary temperatures) $= 178\ BTU$.

Total potential heat entering furnace per pound coal $= 14659 + 178$
$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad = 14837\ BTU$

The intersection of the 14,837 BTU line with the heat capacity curve in Fig. B gives the furnace temperature 2605° F., uncorrected for radiation.

The temperature in a furnace where the fuel bed radiates to the heating surface of the boiler can be estimated by combining a radiation curve with the heat capacity curve of Fig. B. As stated by *Demlein*, when equilibrium is established, the heat corresponding to the reduction of the combustion temperature is equal to the heat radiated by the fire bed at the reduced temperature, which is

$$H = \left[\left(\frac{T_1}{1000} \right)^4 - \left(\frac{T_2}{1000} \right)^4 \right] R\,C\, \frac{G}{W}$$

$H =$ heat radiated per hr. per lb. coal burned
$T_1 =$ true fire temperature, abs. ° F.
$T_2 =$ boiler tube temperature, abs. ° F
$R =$ fraction of heat radiated from the grate which falls on the
$\qquad\qquad$ relatively-cool boiler tubes (see Radiation, page 502).
$C =$ radiation constant ($= 1600$).
$G =$ sq. ft. of grate surface.
$W =$ lb. coal burned per hr.
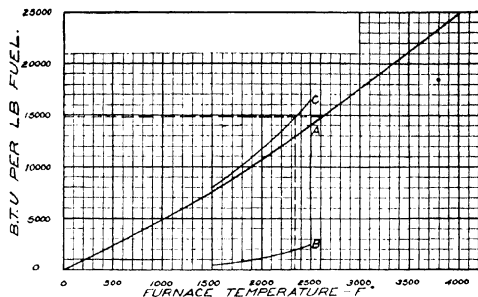
FIG. C. COMBINED RADIATION AND HEAT CAPACITY CURVE

For an example, assume grate surface $G = 50$ sq. ft., 1250 lb. coal per hr., boiler pressure 175 lb. gage, corresponding to boiler tube temperature of 375° F., and $R = 50\%$. The calculation of this fraction of the radiated heat which falls on the boiler heating surface is complicated by the presence of the side walls, but 50% is probably the upper limit for most practical installations. At an assumed furnace temperature of 2000° F.

$$H = \left[\left(\frac{2460}{1000} \right)^4 - \left(\frac{375 + 460}{1000} \right)^4 \right] \times .50 \times 1600 \times \frac{50}{1250} = 1030 \ BTU$$

This gives a point in the radiation curve; after calculating for several other temperatures, curve B in Fig. C is plotted. Curve A in Fig. C is the combustion curve from Fig. B, while curve C is the sum of A and B.

The horizontal dash line (14,837 BTU) represents the total heat entering the furnace per pound of coal. Its intersection with curve C gives the true furnace temperature as 2330° F., as against 2605° F. without radiation.

See discussion of radiation error under flue gas temperature, page 192.

For rough work the thermal capacity of an average flue gas can be assumed to lie between that of CO_2 and N_2 as given in Fig. A, nearer to the N_2 line. Multiplying the values at different temperatures by the lb. gas per lb. coal gives the data for a heat capacity curve like A in Fig. C. Curves B and C in Fig. C are easily calculated as explained above, and the intersection of C with the horizontal line for heat input per lb. of coal gives the true furnace temperature.

Jos. W. Richards calculated the temperatures through a bed of fixed carbon burning on a grate, neglecting the effects of moisture in the air, conduction and radiation, and heat carried off in ashes. If the bed is of just the proper thickness, in relation to the air supply, for the carbon to take up all the oxygen and yet be completely converted to CO_2, and if we assume that the carbon is divided into ten horizontal layers, each of which takes up $\frac{1}{10}$ of the oxygen in the ascending current, the temperature excess at various points over that of the cold entering air would be as shown in the lower half of Figure D. If there are additional layers of carbon above this, as in a gas producer, and if in each layer of this reduction zone, $\frac{1}{10}$ of the CO_2 is reduced to CO, until the exit gases consist of CO and N_2,

the temperatures would be as in the complete diagram. If the bed is deeper than necessary to complete the reduction, the topmost layer of carbon active in reducing the CO_2 would be preheated, and would have a temperature 3040° F. above that of the cold air, while if fired onto the bed at this point without preheating, a lower temperature would be reached, due to the abstraction of heat from the gas in heating the cold carbon The chart gives a good approximation for the temperature at the top of a producer, but in the case of a steam boiler furnace the radiation from the fuel bed to the tubes or other cold surfaces should be kept in mind. *Richards* states that in boiler practice, where much heat is recovered by radiation, the maximum temperature should always be sought, and that it is better to have a thick bed than one that is too thin, admitting secondary air above the bed to burn any CO which may be formed in the upper zones.

Temperatures above that of cold entering Air °F
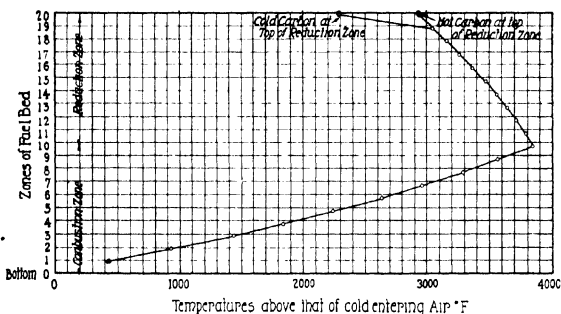
D   TEMPERATURES IN BED OF FIXED CARBON
—*Feuerungstechnik*

The table by *Schulte* gives the theoretical combustion temperature of the volatile constituents of coal as a function of the total volatile content of the ash-and-water-free coal, the air supply and the water content of the coal. Ash does not affect temperature in combustion space. Temperatures are highest in the case of coal containing an average of 15 to 25% of gas and these temperatures fall off regularly on both sides but decline more in the case of gas coals, being about 270° F. lower with lignites than with rich coals. As the excess of air increases, a practically uniform drop in temperature takes place. At the same time the excess of air acts as an equalizer in that the values come closer together with increasing excess of air. The water content of the fuel is of the utmost importance. Its influence is less strongly apparent where the gas content is very great, so that lignites, notwithstanding their high water content, produce comparatively high temperatures, but in the case of fuels low in gas, lean coals, and anthracites, there occurs such a sudden drop in the temperature curve that even with the moderately-low water content of the coal there may be a drop below the temperature of ignition. This is the reason why watery lean fuels are so hard to ignite and so difficult to maintain in the state of com-

bustion. It is, however, important to emphasize that the combustion temperature of the gas is not the only factor that determines the temperature of the ignition arch, the radiation from the glowing bed of coke producing also an influence in this direction. In the case of lean fuels the influence of this radiation from the coke bed is greater and this counteracts the unfavorable influence of the high water content. Attention should be called to the generally well-known fact that a certain water content favors the combustion of lean fuels. The actual cause of the phenomenon is not yet clear, but it is probably due to the catalytic influence of the water vapor.

THEORETICAL FLAME TEMPERATURES, ° F.—*Schulte*

% Moisture in Coal	% Excess Air	% Volatile Constituents in Pure Coal Substance				
		5%	10%	30%	50%	70%
0	0	3920	3950	3885	3715	3355
0	25	3425	3450	3345	3220	2965
0	50	3020	3010	2905	2805	2625
0	75	2730	2705	2615	2515	2355
0	100	2445	2425	2365	2265	2130
10	0	3110	3470	3640	3515	3180
10	25	2730	3055	3165	3055	2795
10	50	2480	2715	2775	2685	2490
10	75	2245	2425	2490	2390	2220
10	100	2050	2190	2235	2165	2030
20	0	2390	2975	3370	3165	2965
20	25	2155	2625	2930	2855	2595
20	50	1930	2355	2590	2505	2325
20	75	1760	2110	2325	2265	2065
20	100	1625	1930	2100	2040	1895
30	0	1670	2420	3025	2970	2670
30	25	1690	2185	2675	2625	2365
30	50	1400	1965	2385	2335	2145
30	75	1290	1780	2140	2080	1900
30	100	1185	1545	1930	1895	1750
40	0				2660	2335
40	25				2350	2090
40	50				2110	1895
40	75				1895	1705
40	100				1715	1555
50	0				2230	1940
50	25				1995	1750
50	50				1795	1600
50	75				1650	1465
50	100				1690	1335
60	0				1735	1465
60	25				1580	1320
60	50				1435	1210
60	75				1300	1120
60	100				1200	1030

W. Trinks gives the charts on pp. 182, 183 and 184 for flame temperatures from the combustion of various fuels. The temperature of the entering air is given at the bottom; the fuel is assumed to enter cold, except blast furnace and clean producer gas, which are admitted at the same temperature as the air. Of the charts for raw producer gas, the first and the first half of the second are for gas at 1000° F., the second half of the latter is for gas and air admitted at the same temperatures for temperatures over 1000° F. The upper curves in all charts show the ideal flame temperatures for air entering at the temperatures indicated, with theoretical amount of air and with different amounts of excess or deficiency of air. Blue water gas, which is the richest commercial gas, does not reach as high a flame tem-
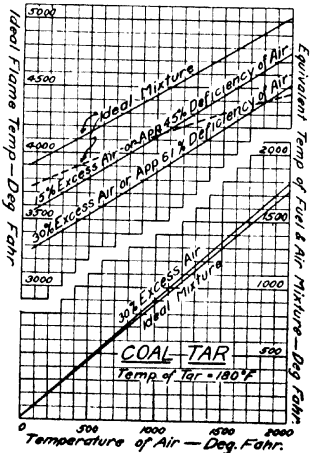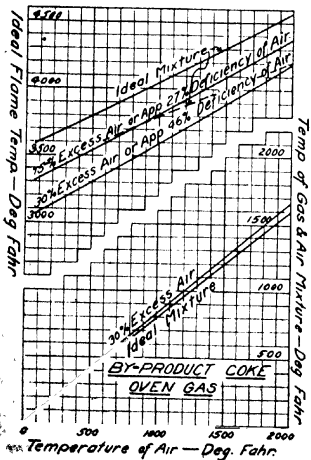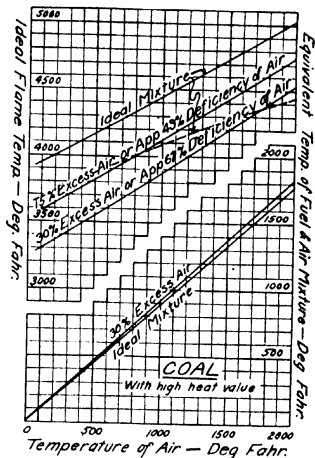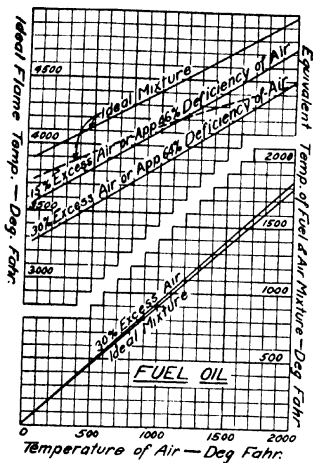
FLAME TEMPERATURES AS AFFECTED BY TEMPERATURE OF
ENTERING AIR.—*Fuels and Furnaces*
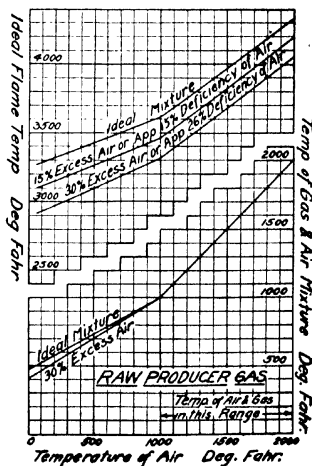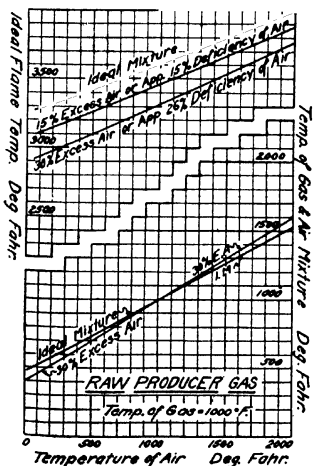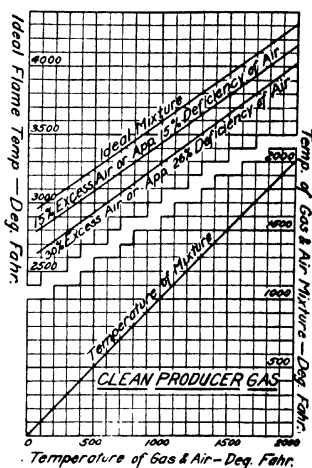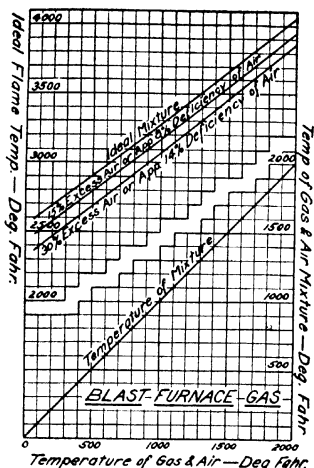
FLAME TEMPERATURES AS AFFECTED BY TEMPERATURE OF
ENTERING AIR—*Fuels and Furnaces*
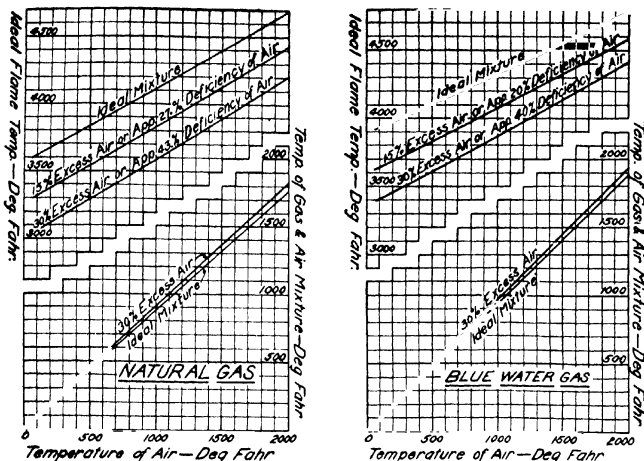
FLAME TEMPERATURES AS AFFECTED BY ENTERING AIR

perature when burnt with cold air as does lean blast-furnace gas with air and gas preheated to 2000° F. Some of the charts contain a dotted line showing the ideal flame temperatures attained with correct mixture of fuel and air, considering the temperature drop due to dissociation of CO_2 and H_2O.

For an approximation to the actual flame temperature in metallurgical furnaces multiply the excess of the ideal flame temperature over the temperature of the entering fuel and air mixture by 0.60 for good mixing and quick combustion, or 0.48 for slow mixing, and add to the mixture temperature, if the *furnace* temperature is above that of the mixture. If the furnace temperature is below the mixture temperature, multiply the excess of ideal flame temperature over furnace temperature by 0.65 for good mixing or 0.55 for slow mixing, and add to the furnace temperature.

TEMPERATURE MEASUREMENT

The preliminary draft of the *A.S.M.E. Test Code* lists the following types of temperature measuring instruments, with range and accuracy when properly installed and used:

(a) Glass thermometers, with mercury, alcohol, pentane, or other organic liquids.

(b) Pressure-gage thermometers, with vapors or liquids as the actuating fluids. There are two classes of these thermometers: (1) the vapor-pressure type partially filled with liquid ether, sulphur dioxide, ethyl chloride, methyl chloride, etc.; and (2) those completely filled with a liquid or a gas, such as mercury, alcohol, nitrogen, etc. Instruments of the first type have scales that are made up of non-uniform divisions, while instruments of the second type have uniformly divided scales.

(c) Differential-expansion thermometers or pyrometers in which the differential expansion of two solids is used as an indication of the temperature.

(d) Electrical-resistance thermometers, with which temperature is determined by measuring the resistance of a calibrated wire.

(e) Thermocouple pyrometers or pyrometers in which the electromotive force set up at the junction of two dissimilar metals is used as an indication of temperature.

(f) Optical pyrometers, with which temperature is determined by matching the luminosity of the hot body with that of a calibrated source or by other means which utilize the visible radiation emitted from a hot body.

(g) Radiation pyrometers, with which temperature is determined by absorbing radiation of all wave lengths upon a small body and determining the temperature of the source by the temperature attained by the absorber

(h) Fusion pyrometers, with which temperature is determined by noting which of a series of materials with graduated fusion temperatures melt or soften when exposed to the temperature under investigation

(i) Calorimetric pyrometers, with which temperature is determined by noting the quantity of heat removed in bringing a body of known thermal capacity from the temperature to be measured to some lower known temperature.

(j) Color-temperature charts, with which temperature is estimated by comparing the color of a luminous hot body with colors given on the chart.

RANGE OF INSTRUMENTS

Type	Range, °F.	Accuracy, °F.
(a) Glass Thermometers		
Ordinary glass, mercury-filled	− 38 to 575	1 to 2
Jena glass, mercury and nitro gen-filled	38 to 1000	2 to 10
Quartz glass mercury and nitrogen-filled . ..	−38 to 1000	2 to 10
Ordinary glass, alcohol-filled.	− 100 to +100	0 5 to 2
Ordinary glass, pentane-filled	− 300 to +70	0 5 to 2
(b) Pressure-Gage Thermometers		
Vapor-Pressure Type·		
Alcohol-filled .	200 to 400	2 to 10
Ether-filled	100 to 300	2 to 10
Sulphur-dioxide-filled	20 to 250	2 to 10
Liquid Filled or Gas-Filled Type.		
Alcohol-filled . . .	−50 to 300	2 to 10
Mercury filled .	−38 to 1000	2 to 10
Nitrogen-filled .	200 to 1000	2 to 10
(c) Differential Expansion Thermometer	300 to 1000	Uncertain
(d) Electrical Resistance Thermometer	− 300 to 1800	.001 to 10*
(e) Thermocouple Pyrometers.		
Base metal	−300 to +2000	.02 to 20*
Rare-metal	0 to 2800	0.1 to 20*
(f) Optical Pyrometers	1100 up	5 to 10 for black-body conditions
(g) Radiation Pyrometers	300 up	20 to 30 for black-body conditions
(h) Fusion Pyrometers	1100 to 3600	20 in best makes
(i) Calorimetric Devices	100 to 2500	Uncertain
(j) Color-Temperature Charts	800 to 2900	Uncertain

*Depends upon indicating instrument.

The "bulb" or sensitive element in those types requiring immersion in the material whose temperature is to be measured must be so located as to acquire and maintain as nearly as possible the temperature of the material under consideration. When the material in which it is immersed is substantially at rest, care must be taken to insure that the material in contact with the thermometer has the same temperature as the main body of the substance; as for example, by stirring a liquid before reading the temperature. When the material is in motion the possibility of stratification or of stagnant portions must always be considered in choosing the location and method of installation of the bulb. Methods which do not involve the use of thermometer wells are to be preferred. When used the following precautions must be observed, particularly when the temperature differs 50° or more from that of the surroundings:

(a) The part of the well projecting beyond the container must be as small as possible so as to eliminate heat transfer to or from surroundings.

(b) The exposed parts of the well should be covered with thermal insulating material of a kind appropriate to the temperatures being dealt with. The pipe wall or equivalent should also be well insulated for some distance from the thermometer well if this is not already the case and if the placing of such insulation will not materially affect the conditions of the test.

(c) The thermometer well should ordinarily be so constructed that it has the smallest possible metallic section consistent with the necessary strength just inside the wall of the pipe. This will tend to reduce the quantity of heat which can flow along the well with a given temperature difference, and, conversely, will tend to maintain the maximum possible difference of temperature between opposite ends of the well.

(d) The part of the well exposed to the medium whose temperature is to be determined must have the necessary surface to permit it to absorb heat as fast as it is lost from the exposed end (or to dissipate heat as fast as it is absorbed at the exposed end) without necessitating a temperature head in excess of that consistent with the degree of accuracy being sought.
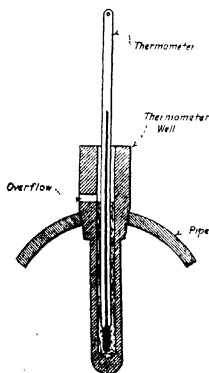
1. PLAIN MERCURY WELL   2. FINNED MERCURY WELL
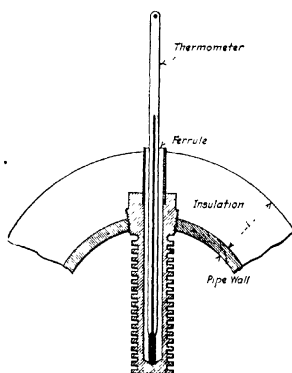
—A.S.M.E.

Plain wells, Fig. 1, are used in measuring temperatures of liquids or saturated vapors; finned wells. Fig. 2, with gases or superheated vapors. The fins compensate more or less for the lower rate of transfer from the gas to the bulb as compared with that from a liquid. When the temperature is low, so that oil does not vaporize, and is so nearly constant that the time lag resulting from its comparatively low thermal conductivity is not significant, oil may be used in the well Solid material, such as graphite, should never be used if any liquid is available The most satisfactory filling materials to be used in iron wells are as follows

TEMPERATURE RANGE, ° F.	MATERIAL
Up to 500	Mercury
500 to 1000	Solder
600 to 1800	Tin

Calibration should be made with the same condition of well as in service. When bare (unprotected) thermocouples or resistance thermometers or other forms in which the sensitive element is connected to an indicator of some sort by metallic wires or tubes are immersed in material having a temperature greatly different from that of the region through which the metallic connector runs on its way to the indicator, conduction of heat along such metallic parts should be minimized by running them for a sufficient distance through an isothermal zone. Imagine, for example, that gas is flowing through a flue of circular section as shown in Fig. 3 and that the temperature falls rapidly from the center toward the wall. If a couple is used to measure the temperature of the gas at the center of the flue and is installed so that the leads run radially outward as indicated at A, the temperature indicated will be lower than the real temperature for reasons already explained If, however, the leads are run along the center line of the flue for sufficient distance, as shown at B, the error will be reduced to a negligible amount. The same precautions are necessary with respect to any clamps or other fastening devices which are used to hold temperature-measuring devices in place The instrument should be thermally insulated from the clamps and the latter should have such a shape that they do not conduct any appreciable quantity of heat away from the sensitive element and also that they do not cause a local drop in temperature of the medium in the neighborhood of the element The same general precautions should be followed in measuring the temperature at any other point in the flue.
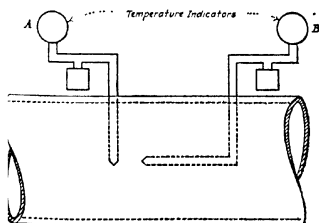
THERMOCOUPLE WITH PARTS
IN ISOTHERMAL ZONE
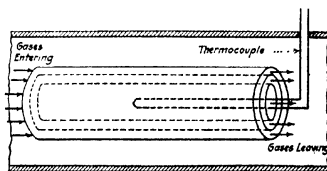
4. SHIELDED THERMOCOUPLE
—A.S.M.E.

When it is necessary to place the sensitive part of a temperature measuring device in a position where it can "see" surfaces at materially higher or lower temperatures than that of the medium in which it is immersed, the installation should be so planned as to minimize errors arising from radiation. When the material is flowing, this can be done by surrounding it with one or more shields of cylindrical section, so placed that the axes of the cylinders are in the line of flow, Fig 4 When there is no definite flow there is theoretically no means of protection against radiation error. However, if shields such as those described are used they will afford some protection if arranged in such a way as to prevent the sensitive element from "seeing" the hotter or colder surfaces, and if the material flows through them by virtue of the convection currents set up by local heating or cooling Arrangements should be so designed as not to produce a larger error than the one they are intended to correct The size of the sensitive element is also of importance Radiation is a function of surface as well as temperatures If the element could be reduced to a geometrical point having no surface there would be no error Therefore the smaller the element under such conditions the better. Dimensions here considered apply to leads or their equivalent, as well as the sensitive element itself Thus a very small thermocouple with very large leads might be very greatly affected by net radiation to or from those leads.

Protecting tubes as used with thermocouples are capable of producing errors of great magnitude if improperly used Such tubes almost always have large external surface so that they exaggerate radiation errors When made of metal they generally have large metallic cross-section and are therefore good thermal conductors, so that they cause errors of the type described in connection with thermometer wells If a thermocouple is merely suspended in such a tube near the closed end its temperature must of necessity lag behind that of the tube wall, so that if rapid temperature variations are occurring the thermocouple is probably never very near to the temperature of the material being measured.

If the temperature of the water entering the boiler is greatly different at low rates of flow from what it is under normal conditions, it should be measured every time that a stated amount of water has passed a certain point in the feed system, such as once every time or every second time that the weighing tanks at the feed-pump section are emptied

Irving B. Smith states that copper and constantan thermocouples are suitable for temperatures up to 320° C. (608° F.), and can be relied upon to remain constant to within 0 5° C. (0 9° F.) after they have once been calibrated. Even up to 500° C. (932° F.) they will be found accurate and reliable; the copper element oxidizes rapidly at such high temperature but can be renewed without recalibration of the instrument. There need be no fear of errors of appreciable magnitude from cooling by conduction along the couple wires when they are of No. 22 B.&S. gage or smaller, provided the hot junction is in intimate contact with the bath. In checking a thermocouple, it is sufficient simply to twist the couple wires together, without soldering or welding, if a potentiometer method of measurement is used, as the only effect of the high resistance is to reduce the sensitivity of measurement, although this practice would be unsafe when measuring with a millivoltmeter.

Iron and constantan couples are serviceable up to 1000° C. (1832° F.), and, with a potentiometer instrument, maintain their calibration even though

the iron is oxidized to the point of nearly opening the circuit. For use under severe atmospheric conditions, the iron can be calorized. From 1000° C. to 1400° C. (1832° F. to 2552° F.), chromel-alumel couples have been found serviceable, and, above this, couples of Pt and Pt-Rh must be used.

A millivoltmeter method of measurement is less precise and reliable but is direct reading and more readily comprehended by the layman. Whether calibrated in millivolts or directly in temperature, it cannot as a rule be checked except in conjunction with its proper lead wires, as the calibration includes the potential drop along the leads as well as the emf set up at the hot junction. If total resistance has doubled, a potentiometer capable at first of balancing to 0 5° C. would be reduced so in sensitivity as to balance to 1° C., while a millivoltmeter would show an error of nearly 50° C. at 100° C. This is not readily determined with a millivoltmeter unless the whole is checked at some known temperature, but such an error is readily checked with a potentiometer by simply throwing the dial somewhat off the balance position and noticing from the deflection of the instrument to what extent the sensitivity is impaired by the unusually high circuit resistance. In measuring temperature with a thermocouple there is, in general, an error introduced due to conduction of heat to or from the hot junction. With a good thermal connection between a couple, and a good heat conducting solid or liquid, no trouble is experienced with couples of small dimensions. The use of iron-constantan thermocouples at high temperatures creates a region of inhomogeneity where the steepest temperature gradient exists, which becomes a source of local emf. To avoid error from this source in checking or in future use the couples should be immersed to at least an equal depth. Parasitic currents arising from bends and twists are small enough to neglect when using small wires and measuring temperatures of but a few hundred degrees C. Errors due to changes in the cold-junction temperature can be eliminated in an instrument having an automatic compensator. The determination of gas temperatures in economizers has been made by means of thermocouples arranged in series and so disposed as to secure an approximation to the average temperature of the gas, with the various cold junctions brought out to a convenient point where a compensator is applied, and before and after temperatures are recorded.

With a couple projecting into hot gases a distance of 18 in., conduction error may be ignored. The couple should be placed in a substantial steel tube for mechanical strength, but the couple wires should be exposed for 6 in. and should not be larger than No. 22 B. & S. gage, such apparatus permitting measurement of flue gas temperatures of 200° to 250° C. (392° to 482° F.) with an accuracy of 3 to 5° C. (5 to 9° F.). In the last pass of a boiler where the temperature of the gas may be 650° to 750° C. (1202° to 1382° F.) radiation from the couple to the colder boiler tubes may cause a reading which is 25° C. (45° F.) low. Experience indicates that at this point a correction approximating 3% will leave only a small outstanding error, and in the downtake about 1% should be added. Multiple couples can be used to obtain an average for different points across a passage. A thermocouple used for measuring the temperature of superheated steam records a sudden drop whenever water is carried along with the steam.

A. THERMOCOUPLE FOR FEED-WATER LINE

Feed water temperatures are usually determined with a mercurial thermometer placed in a mercury or oil well, but these are often difficult of access and do not afford an automatic record. A thermocouple built like a spark plug, Fig. A, with automatic cold-junction compensator, can be used for this service, as with the tapered and insulated leads the internal pressure acts to prevent rather than produce leaks, and the intimacy of contact with the water whose temperature is measured insures against errors. Similar couples, with mica plug insulation, can be tapped directly into boilers, and used for study of temperature distribution throughout tubes and drums.

Radiation and Optical Pyrometers.—*White* and *Taylor* give the following table of the temperatures corresponding to different colors of light emitted from the furnace:

Character of Light	Temperature ° F.
Dark red, blood red, low red	1050
Dark cherry red	1175
Cherry red	1375
Bright cherry, light red	1550
Orange	1650
Light orange	1725
Yellow	1825
Light yellow	1975
White	2200

Optical pyrometers can be used for obtaining the temperature of the furnace and the combustion chamber, provided it is not necessary to look through flame or smoke. The *Leeds & Northrup* Optical Pyrometer is based on the principle that the intensity of light from incandescent bodies varies in a definite manner with the temperature. Light from the incandescent body is compared with a standard source. The eye is very sensitive in judging which is the brighter of two areas, especially when one is small and superimposed on the other. The two areas can be made of equal brightness, either by varying the amount of light admitted from the incandescent object, or by varying the intensity of the standard. The latter method is preferred by the *U. S. Bureau of Standards,* and is applied in this pyrometer, shown on page 191. *L* is a lens through which radiation from the incandescent body whose temperature is to be measured is brought to a focus at the point *F.* A tungsten lamp filament is placed at *F* in the plane of the image. This filament receives current from a small storage battery contained in a portable case, together with a rheostat and an accurate milliammeter. The incandescent filament and the image produced by the lens are observed through the eye-piece. The current through the lamp is adjusted by the hand rheostat until the filament becomes indistinguishable against the hot object. The adjustment can be made with great accuracy, for the effect of radiation upon the eye varies 15 to 20 times faster than the temperature. The milliammeter can be provided with a scale to read in degrees of temperature, or the temperature can be obtained from a calibration curve supplied with the instrument. The red glass
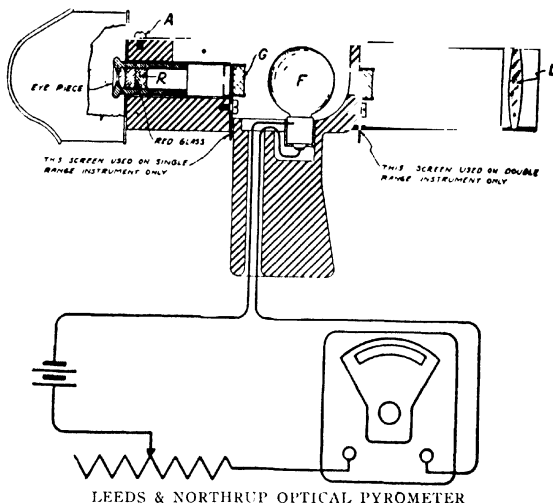
LEEDS & NORTHRUP OPTICAL PYROMETER

placed in the eye-piece overcomes the dazzling effect, and eliminates any question of matching colors For temperatures above 2500° F., the light received through the lens would be blinding. The instrument is therefore fitted with a screen which can be turned into place for reducing the light admitted from the hot body A large surface to sight at is not required, and distance makes no difference. All bodies when enclosed within a furnace of the same temperature emit "black body" radiation, and their temperatures can be read directly. The same is true of some bodies, such as carbon, in the open, also approximately of iron and steel in the solid state For bodies which glisten, as molten metals, a correction factor must be used, if they are viewed in the open.

The *Ardometer* is a radiation pyrometer in which the "total radiation" of a definite area of the body to be examined is concentrated upon a thin, blackened platinum disk soldered to the hot junction of a small thermo-element, the generated emf sending a current through the circuit, which causes a galvanometer deflection which is proportional to the fourth power of the absolute temperature of the body sighted upon. It is used for indicating or recording temperatures from 2000° to 4600° F.

ARDOMETER

S₁   O₁   W O₂   S₂

L

K   Z

N

Ilan

S₁   O₁   W O₂   S₂

L   b

d   K   Z   N

Elevation
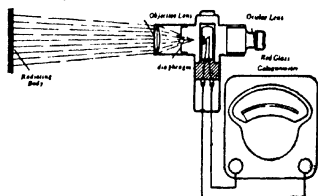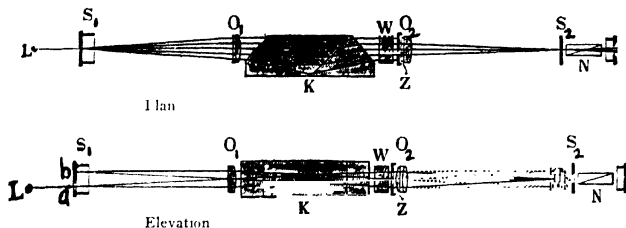
PRINCIPLE OF WANNER OPTICAL PYROMETER

The Wanner Optical Pyrometer, which has been used by the *Bureau of Mines,* operates as a photometer, comparing the light from the furnace, observed through the opening *b,* with that from a standard lamp *L,* forming a part of the instrument, and observed through *a.* The light from both sources is diffracted by the compound prism *K,* so placed with regard to the lenses *O₁, O₂* and *Z* that all rays of the spectrum except the red hydrogen lines are intercepted, and the two bands of red light are observed one above the other, at *S₂.* The Wollaston prism *W* serves to polarize each into perpendicular components, and the analyzer *N* is turned until the two bands appear to the observer to be of equal brilliance, the amount of rotation of *N* being a function of the temperature of the hot body. The standard source is a 6-volt incandescent lamp illuminating a ground glass surface and operated by a three-cell storage battery. From time to time the standard is calibrated by comparison with a lamp in which amyl-acetate is burned. The pyrometer is used either in the hand or mounted on a tripod.

Gas Temperatures.—In reading flue-gas temperatures, care should be taken to secure the average. The temperature should be taken at the same point as the gas sample, i. e., where the gases leave the heating surfaces of the boiler. This is especially important in obtaining an accurate heat balance, for if air leakage takes place after the pyrometer and before the sampling tube, the heat balance will show too great a loss up the stack. The bulb must be in the path of the moving gases, and must be in place long enough to assume the full temperature of the gases.

Great caution is called for in measuring the temperature of gases surrounded by bodies at different temperature, on account of **radiation effects.** For example, if a pyrometer or thermometer is placed between the tubes of a boiler, it will read low. *Kreisinger* and *Barkley* state that there is ordinarily an error of from 5 to 25% in temperature readings of a stream of hot gases surrounded by colder or hotter surfaces. Radiation is the chief cause of the error, and the most difficult to overcome. If a temperature measuring instrument is immersed in hot gases surrounded by cooler surfaces, it absorbs heat by convection, and its temperature rises. Gases are permeable to radiation and as soon as the temperature of the instrument exceeds that of the surrounding surfaces, heat passes from it to them through the gases by radiation. The temperature of the instrument continues to rise with a decreasing rate until the quantity of heat it gives off
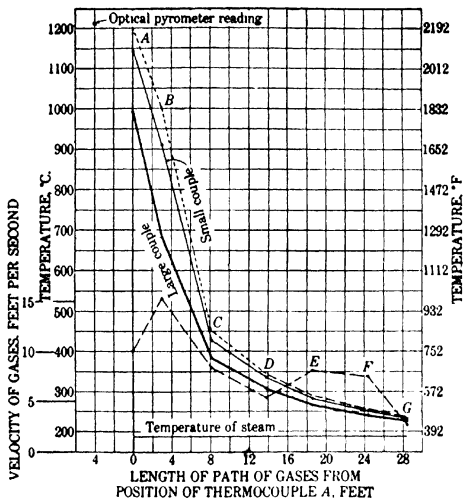
TEMPERATURE READINGS AS AFFECTED BY SIZE OF THERMOCOUPLE

The heavy curve connects readings obtained with a couple 0 5 in. in diameter and the light curve readings obtained with a couple 0 008 in in diameter. Dotted curve is estimated true temperature of gases Curve drawn in dashes shows approximate velocity of gases.

by radiation is equal to the quantity it receives by convection. The temperature then remains constant, but is below the temperature of the gases. The magnitude of the error depends mainly on

1. The size of the part of the instrument exposed to the gases and to radiation,

2. The difference between the temperature of the gases and that of the surrounding surfaces, and

3. The velocity of the gases.

The smaller the exposed part and the smaller the difference of temperature, the smaller the radiation error. Of all temperature measuring instruments, the thermocouple can most easily be reduced in size. It can be made so small that the radiation error is negligible for practical purposes, the assumption being that a couple having an exposed hot junction made of wires of zero diameter would indicate the correct temperature. The curve above indicates the effect of the size of the thermocouple on the temperature reading. A, B, C, etc., represent locations in a B. & W. boiler setting at the Carnegie Technical School. The large couple was 0.5 in. in

diameter, and the small couple 0.008 in. in diameter. The dotted curve represents the true temperature of the gases as computed for a couple having zero diameter wires. The dash curve at the bottom gives the approximate velocity of the gases. The boiler was gas-fired, and the volume of gases is computed from the volume of gas burned, the chemical analysis of the products of combustion and flue temperature of the gases. The small black dot at the top left-hand corner represents the furnace temperature as observed with a Wanner Optical Pyrometer sighted through one of the gas burners. The small couple indicates temperatures much closer than does the large one At position B the large couple showed a radiation error of 575° F., whereas the small one showed a radiation error of 150°. In position F, where the temperature of the gases is much lower, the large couple read about 25° F. low, while the small couple showed an error of only 5° F. low.
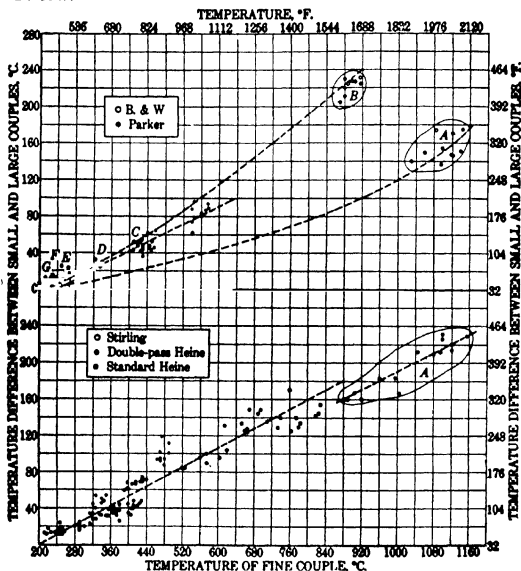
EFFECT OF TEMPERATURE OF GASES ON RADIATION ERROR IN VARIOUS TYPES OF BOILERS

The above figure shows how much lower large couples read than do small ones when placed in actual boiler settings on common types of water-tube boilers. With the exception of the group marked A, all readings were obtained with a thermocouple placed among the tubes, i. e., in

places totally exposed to the heating surface of the boilers. Group *A* for the B. & W. boiler was taken with couples placed below the boiler tubes in the combustion space. The couples were partly exposed to the tubes, and partly to the brick wall, which latter was hotter than the tubes. The couples therefore did not have as large a radiation as if they had been completely surrounded by the boiler tubes. Group *A* for the Stirling boiler was taken with couples placed one foot above the arch, and one foot from the front nest of tubes. The couples were therefore partly exposed to hot brick work, and therefore their radiation is smaller than if completely surrounded by cooler tubes.

From experiments on four different sized couples, *Kreisinger* and *Barkley* state that as the diameter of the hot junction of the couple decreases, the temperature indicated by the couple rises, at first very slowly, but after the diameter of about 1/10 inch is passed, this rise in temperature becomes very rapid, and also the greater the difference between the temperature of gases and that of the surrounding surfaces the quicker the rise. It is possible to plot a curve showing the relation between diameter of couple and temperature indicated, and from this arrive at the true temperature which would be indicated by a zero diameter couple. It is also possible to compute this curve mathematically. By placing the thermometer within a hood of a non-conducting material through which the gases circulate, the radiation error can be reduced to a negligible quantity, but the method does not necessarily give the average temperature of the flue gases, because of their possible stratification. The true temperature of gases in different parts of the section of the up-take may vary over a considerable range. The most accurate method appears to be the use of a number of thermocouples of very small wires, each of which may be shielded by a non-conducting hood screening it from hotter or colder surfaces. The *Bureau of Mines* has used a sort of crow-foot collector (see page 247) which brings gases from several points in the flue to one point where a small-wire thermocouple is placed.

An example of the error from placing the bulb of a mercury thermometer among the tubes of a boiler was found in a Pittsburgh plant, where the engineer showed a series of results giving the steam pressure as 162 lb, flue-gas temperature as 386° F. and efficiency as 78%. The temperature corresponding to 162 lb. is 371°. Apparently the flue gas was only 15° hotter than the water in the boiler. It was found that the thermometer had been inserted among the tubes of the third pass of a B. & W. boiler, and really measured the temperature of the surrounding tubes. The actual temperature of the gases was probably 200° or 300° higher.

Another instance of low flue-gas temperature readings was found in a test of a Stirling boiler at the Williston plant of the U. S. Reclamation Service. The thermometer was inserted through a door in the rear of the setting, about 3 ft. below the damper. The distance from the door to the rear steam drum was 18 in. The thermometer therefore radiated to the door, the drum and the damper, as well as to a set of air pre-heating tubes just below the thermometer. The temperature of the pre-heater tubes was probably 150° F., that of the steam drum 352°, that of the rear door about 100°, and the temperature of the damper probably 500°. A second thermometer placed in the stack about 4 ft. above the damper indicated a temperature of about 100° higher than the thermometer in the up-take. The *Bureau of Mines* therefore used the funnel or crow's foot apparatus

for collecting average gas samples, mentioned above. Gas temperatures taken in this were fairly correct.

Often great care is taken to calibrate a flue-gas thermometer and then it is placed carelessly in the up-take or boiler setting. The correct measurement of gas temperatures is really a high art.

Value of Temperature Readings.—*P. C. Linde* suggests that if each boiler is equipped with pyrometers, so that the fireman can ascertain the temperature in each pass, he can tell the condition of the furnace and the boiler; that is, whether the fires are dirty, and whether they have holes in them, whether the boilers are dirty inside or outside, whether the baffles are breaking down. However, he cannot tell which one of these troubles is producing the effect. The flue-gas temperature will indicate the necessity of cleaning the boilers. The temperature at full load should be taken at specified times, say every 24 hours. The temperature immediately after cleaning the boiler can be used as a standard. If the flue-gas temperature is say 150° higher for full load than the standard, or the economizer gas temperature 100° higher, the boiler needs cleaning or attention to baffles.

In *Bureau of Mines* tests on a large number of coals the flue-gas and combustion chamber temperatures rose and fell together. The *University of Illinois* made tests on a Heine boiler with T-tiles, which leave the undersides of the tubes in the lowest row bare, and with C-tiles, which completely encircle the lower row of tubes, with the following results:

	C-tile	T-tile
Capacity	102 8%	104%
Efficiency	65.6%	68.5%
Temperature above fuel bed	2066° F.	1883° F.
Flue-gas temperatures	588° F.	467° F.
CO_2	6.8%	7.5%

Assuming a constant specific heat of the flue gases, and neglecting radiation losses, the efficiency of a boiler as an absorber of heat from the gases is equal to

$$\frac{t_1 - t_c}{t_1 - t_b}, \text{ wherein}$$

t_1 is the temperature of the gases just before contact with the heating surfaces,

t_c is the temperature of the gases just after leaving the heating surfaces, and

t_b is the temperature of the boiler.

The heat utilized increases with increase in the temperature in the combustion chamber, but with decrease in the temperature of the waste gases. Flue-gas temperatures increase faster than the load.

CLINKER

The subject of ash fusing temperature, which determines the clinkering tendencies of a coal, is treated on page 64. The *Bureau of Mines* names the following as usual causes of clinker trouble: thick fire, excessive stirring of the fire, burning coal in the ash-pit, much slack in the coal, closed ash-pit doors and the preheating of air admitted under the grates.

Any coal will clinker if the ash is heated to the fusing temperature. Ash in an oxidizing atmosphere, as near the bottom of the fuel bed, has a higher melting point than in a reducing atmosphere, as near the top of the fuel bed. The difference is as much as 260° F.

A thick fuel bed causes clinker trouble as often as all other causes put together. A thick fuel bed cuts down the air supply and permits the ash to become heated. Air in passing through the grates and the fuel bed absorbs heat from the grate bars and the ash upon them, thus keeping them relatively cool. The fusing temperature of the ash is lowered by the reducing atmosphere in the upper layer of the ash. In a thick bed the ash mixes with the burning coal to a greater height, and the reducing zone is nearer the grate, due to the lower velocity of the air. In a thin fire the reducing zone is confined to the top inch or two of the fuel bed, where bits of ash are few and far apart, and cannot fuse together.

The second greatest cause of clinker trouble is stirring of the fire. If a caking coal is fired in large amounts it fuses. Breaking up the crust with a bar brings the ash to the upper part of the fuel bed into the reducing atmosphere, where it fuses more readily and produces clinker. Careless leveling of the fire with the rake may produce the same result. Burning coal may be shaken through the grate when leveling the fire or when attempting to fill up the holes with fresh coal. This overheats the grate bars and the ash, and clinker is very liable to result.

A large quantity of slack tends to fuse, cutting down the air. The result is the same as a thick fire, the grates and layer of coal are overheated. Closed ash doors and preheating the air have an effect similar to the above and the grates and ash are overheated. With coals forming large pieces of clinker it is always a question whether more heat is not lost by frequent cleaning of the fire than by the bad condition of the fuel bed on account of its clinker. Overall efficiency drops with increase in ash percentage. High ash reduces the capacity of the boiler by reducing the rate of combustion, and also by the fact that during the time of removing the clinker combustion is almost entirely suspended.

The following general suggestions are given to aid in overcoming clinker trouble: If possible find and remove the cause. Use thin fires; keep the fire bed level by placing the fuel on the thin spots. Avoid leveling with the rake. Above all, omit the slice bar. Fire small charges, thereby reducing the crust formation and the need of breaking it up. Especial care should be taken to do this if the coal contains much slack. Avoid burning coal in the ash-pit. If the pit is tight, keep water in it, otherwise blow in steam. The decomposition of the steam will absorb heat from the grates and the ash. Keep the ash-pit door open. Use the damper to regulate the draft.

Joseph Harrington calls attention to the bad effect of the agitation of the fuel by underfeed stokers when used on high-ash Western coals, tending to form the fused ash into enormous clinkers. These may carry with them an equal amount of combustible, representing 3 to 6% of the total coal fired. With a stoker which does not agitate the fuel nor admit unnecessary air, and which discharges the refuse as formed, high rates of combustion can be secured, and the combustible in the refuse kept down to 10%.

A. Bement describes how Illinois screenings producing very objectionable fusible ash were burned successfully with underfeed stokers, at

200% boiler rating. A ⅜-in. perforated steam pipe was placed along the grate surface next to each side wall to cool the wall and prevent clinker sticking to the wall. Trouble at the dump grate was avoided by not allowing the fire to extend far enough back to keep the clinker hot at that point, using the back air supply, if necessary, to burn it off. The grate was dumped before clinker and ash could come in contact with the back wall, and any large clinkers were broken up with a bar through the side door, being cold and brittle. The avoiding of stirring and slicing with coals containing fusible ash is especially important if it becomes necessary to change over to such coals in plants whose attendants are accustomed to more refractory ash.

DRAFT

The word draft is sometimes used to signify the flow of the gases, but ordinarily it means a depression of pressure. With the ash-pit doors open and the furnace doors closed, a draft gage connected above the fuel bed will indicate a certain reading. When the ash-pit doors are closed, the draft gage will show an increased draft, but the movement of gases will be decreased, because the air supply has been cut off, the total resistance of the system having been very much increased. If the furnace door is opened, air will rush in with considerable velocity, but the draft pressure will have been very much decreased.

With *natural draft,* the reduction of pressure at the base of the chimney is explained by the fact that the column of gases in the stack is lighter than a column of air of equal dimensions outside. The hotter the gases and the higher the stack the greater the difference of pressure.

Induced draft is produced by an exhaust fan placed between the boiler and the stack. The fan causes a reduction of pressure at the fan inlet and the atmospheric pressure in the ash-pit pushes the air through the fire, and the gases through the boiler. With *forced draft,* the ash-pit is put under a pressure greater than atmospheric pressure.

Balanced draft may be defined as a condition where the overpressure in the ash-pit is just sufficient to overcome the resistance through the fire, and the damper is so regulated that the depression of pressure in the uptake due to chimney or induced draft fan will just draw the products of combustion through the boiler, approximately atmospheric pressure being maintained in the firebox, thus eliminating air leakage into the latter.

The pressure relations with several kinds of draft are shown very clearly in the chart on page 199, due to the *Bureau of Mines.*

The following statements discussing the relations between the pressure drop through the fuel bed, the drop through the boiler, and the total drop, also the relations between pressure drops and resistances, are according to the *Bureau of Mines.*

If all of the resistances to the flow of gases remain constant, the pressure drop through any portion of the path will have a constant ratio to the total drop from the ash-pit to the up-take. The pressure drop through the fuel bed, considered in connection with the drop from the firebox to the up-take, indicates the fuel bed resistance.

If the pressure drop from the ash-pit to the up-take remains constant, the pressure drop through any portion of the path will vary in the same direction as does the resistance to the flow in that portion, although the
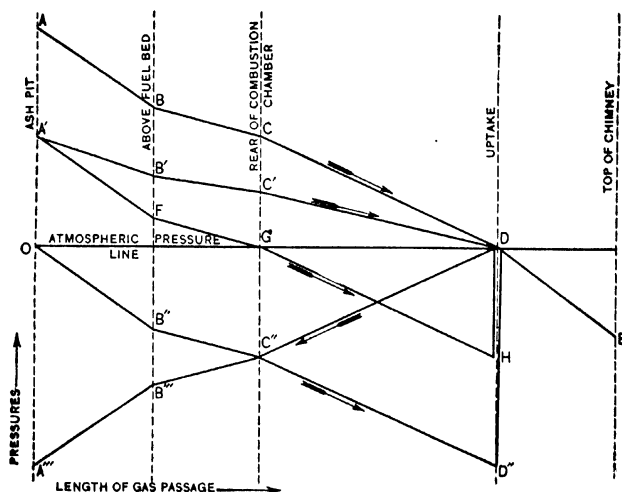
PRESSURE DROP THROUGH A HYPOTHETICAL BOILER EQUIPMENT

The arrows represent directions of flow of gases Line ABCDE represents pressure drops through the equipment when a fan is used to raise the pressure in the ash pit. Line A'B'C'DE represents the pressure drops through the equipment with the same fan running so as to give only half the pressure Line OB''C''D''DE represents the pressure drop through the equipment when an exhaust fan is used to reduce the pressure in the up-take by an amount equal to D''D, the ash-pit being open to the atmosphere. Line A'FGHDE represents the pressure drop through the equipment when both pressure and exhaust fans are used, but run with half the respective pressure effects of the first and third cases above. Line A'''B'''C'''D represents what would be the pressure drop through the equipment if the exhaust fan of the third case above were connected to the ash-pit and the up-take opened to the atmospheric pressure.

magnitude may not be in simple proportion. With the total pressure drop constant, more gas will flow through the boiler as the pressure drop through the fuel bed decreases. Boiler room men ordinarily expect the contrary.

When the resistance through any portion of the path remains constant, the weight of gas passing through that portion varies as some function of the pressure drop through that portion. For example, the weight of gases passing through a boiler is directly proportional to the square root of the drop of pressure.

Since the resistance of the fuel bed is ordinarily the only changeable resistance in a boiler draft problem, it may be said that the weight of gases varies inversely as the resistance of the fuel bed, the total pressure drop remaining constant. Less heat is delivered to the boiler when the resistance

through the fuel bed increases, the initial temperature of the gas and the total pressure remaining constant.

High resistance may be caused by too thick fuel bed; air spaces in the grate filled with slag, or air spaces too small for the coal used; dirty flues and tubes. Draft may be reduced by doors open in the setting, flues, chimney base or air duct; damper stuck or not opening far enough, due to stretch in the cable; nozzles of the steam jet clogged with baked soot, etc., or the air intake for the jets partly closed; and lastly by the chimney and flue being overloaded.

In the following sections each portion of the gas passage in a boiler installation is considered alone, and all are co-ordinated in the section on Stack Proportions, page 209.

DRAFT REQUIRED BY THE FUEL BED

Draft loss through the fuel bed depends upon the kind of fuel, the depth of fire, the method of firing and the rate of combustion. The rate of combustion is the number of pounds of coal burned per square foot of grate surface per hour. Thickness of fire, % ash and air space in the grate also are factors. Only experiment can show their effects.

In general the resistance to flow of air varies as the square of the velocity, but while draft loss through fuel beds increases much faster than the rate of burning, it does not increase exactly as the square of the rate. *Alfred Cotton* describes an investigation of draft resistance in connection with a Heine 9500 sq. ft. longitudinal-drum boiler, fired with a standard 10-retort Sanford Riley underfeed stoker. In Fig. 1 the load and the stoker draft (difference between pressure in the ashpit and above the fire) is plotted against time. The draft and load observations in Fig. 1 are repeated in Fig. 2, together with the average of 41 other runs, some of which were of 24 hr. duration. Above 130% load the curves show that doubling the load requires less than double the draft pressure; and above 300% the draft resistance actually begins to drop. The low rate of increase of draft may be due to the pronounced disturbance of the
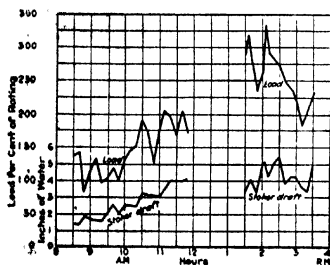
| 1. LOG OF DRAFT AND LOAD | 2. RELATION BETWEEN DRAFT AND LOAD.—*Power* |
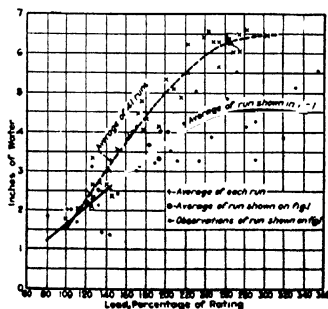
fuel when burning fuel at high rates on underfeed stokers, so that caking and clinker formation is impeded. The lower draft with the run in Fig. 1 is probably due to the wide variations in load in this case, redistributing the clinker periodically. The coal used was a mixture of clinkering Pennsylvania bituminous coals averaging 13,500 BTU. There was no large amount of excess air at the high loads, in fact the CO_1 was higher. At ratings under 100%, with reduced bed disturbance, it is likely that the conventional fuel-bed resistance curves, running back to the origin, would apply.

Tests made by *L. A. Stenger* on the rate of flow of cold air through coals of various sizes and with various dust contents, and on the behavior of the same coals in the furnace, showed that those having limited air admittance gave low efficiency, due to formation of holes and ridges in the bed, causing excess air in places and incomplete combustion in others. Wetting dust-bearing coal practically doubles the air flow. The first experiments with coal of uniform sizes showed that pieces below ⅛-in. caused a very marked decrease in air flow. The effect on air flow of various percentages of dust (*i. e.* pieces less than ⅛ in) in wet coals is shown in Fig. 3.
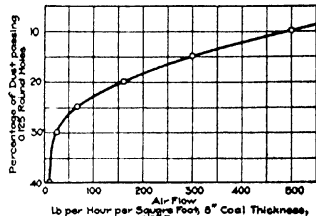
3.   RATE OF AIR FLOW THROUGH COALS HAVING DIFFERENT DUST CONTENTS—*Elec. World.*
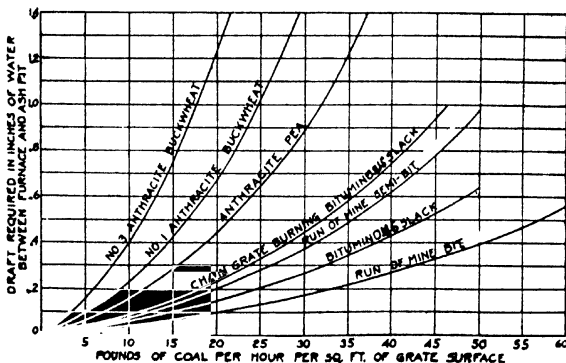
DRAFT REQUIRED BY HAND FIRED FUEL BEDS
—*Buffalo Forge Co.*

The above chart, and those on page 202, show the relation between combustion rate and draft through fuel beds, for hand firing and mechanical stokers.

FURNACE DRAFT FOR DIFFERENT COMBUSTION RATES WITH B & W CHAIN GRATES

FURNACE DRAFT FOR DIFFERENT COMBUSTION RATES WITH GREEN CHAIN GRATES

Total Draft in Inches W. G.

Combustion Rates with Various Fuels

Curve "A" Indicates Coal from Eastern Interior Field Non-Coking
Curve "B" Indicates Coal from Northern Appalachian Field, Coking
Curve "C" Indicates Coal from Southern and Gulf Fields, Coking
Curve "D" Indicates Coal from Northern Appalachian Field Semi-Bit Coking
Curve "E" Indicates Coal from Rocky Mountain and Southwestern Lignite
Curve "F" Indicates Coal from Western Interior and Southwestern Fields
Curve "G" Indicates Coal from Southwestern Field, Semi-Bit High Ash

Draft in Furnace   Inches of Water

CHAIN GRATE DRAFTS.—*Green Engg. Corp.*

DRAFT REQUIRED BY STOKERS

The following table of pressure difference in inches of water required to burn various coals on hand-fired grates is due to *T. F. J. Maguire:*

Rate of combustion per sq ft per hr	Eastern Bit. Slack	Western Bit. Slack	Semi-Bit Run of Mine	Anthracite Pea	Anthracite Buckwheat	
					No. 1	No. 2
10	.06	.07	.07	.15	.20	.39
15	.10	.13	.12	.27	.41	.77
20	.15	.19	.19	.43	.69	1.26
25	.21	.26	.28	.63	1.05	1.90
30	.27	.35	.38	.86	1.50	
35	.35	.44	.49	1.12		
40	.42	.54	.62			
45	.51	.66	.72			
50	.61	.78	.93			

The *maximum* rate of combustion required for any furnace can be computed by the following formula from *Menzin*

$$C = \frac{(HP.) \times 33480}{UEG}$$

C = Maximum weight of coal to be burned in lb. per sq. ft. per hr.

$HP.$ = Maximum horsepower to be developed

U = Calorific value of the coal, BTU per lb

E = The efficiency of the combined steam generator, and

G = The grate surface in sq. ft.

DRAFT REQUIRED BY BOILERS
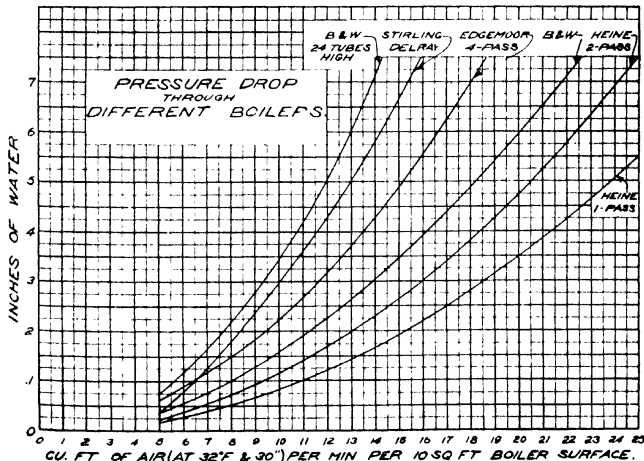
A. DROP OF PRESSURE THROUGH DIFFERENT BOILERS

Per Cent Rating Developed
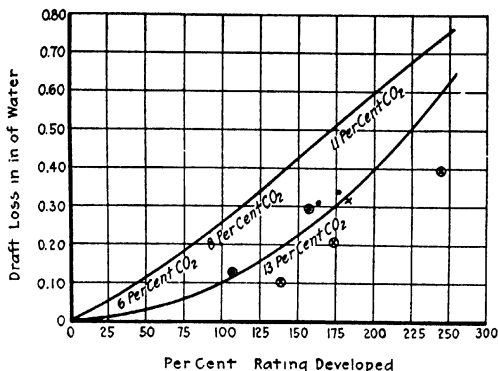
B. DRAFT LOSS FROM FURNACE TO DAMPER OF A CROSS-BAFFLED THREE-PASS EDGE MOOR WATER TUBE BOILER WITH 18-FOOT TUBES, FOR EFFICIENT AND INEFFICIENT FIRING.—*Power.*

Draft loss in boilers depends upon the type and baffling, and increases with the load. According to *Steam*, approximate figures are 0.25 in. with boilers run at rating, 0.40 in. at 150% rating, and 0.70 in. at 200% rating.

The pressure drops through different boilers are indicated on the chart Fig. A, due to *P. A. Bancel*. In general it may be said that the loss at normal rating is approximately 0.25 to 0.3 in. of water for horizontal return tubular boilers, 0.2 to 0.35 for B. & W., 0.51 for Stirling and 0.43 for vertical tubular boilers of the Wickes type. For normal rating consider about 10 to 15 cu. ft. air per min. per 10 sq. ft. of surface, depending on excess air.

Fig. B, by *A. L. Menzin*, draft loss for an Edge Moor boiler, is fairly representative of the draft required by boilers. The lower curve is applicable to boilers 15 tubes high without superheaters. The points in circles are for boilers 14 tubes high, with superheaters over the first and second passes. The circumscribed crosses are for boilers 13 tubes high, also with superheaters. The upper curve was constructed from the lower by allowing for increased air, but at a decreasing rate for increasing overload. While it is not unusual for a boiler to develop its rated capacity with 8% CO_2, it is hardly to be expected that a boiler will develop 175% of rating with less than 11% CO_2. The upper curve is representative for ordinary firing under unfavorable conditions, while the lower is for good firing. The upper curve should be used ordinarily for chimney calculations.

Fig. C, by *Orrok*, shows the draft for B. & W. boilers in comparison with an Edge Moor boiler.

Percent rating
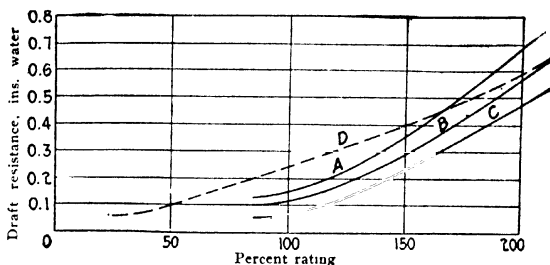
C. DRAFT RESISTANCE, B. & W. AND EDGE MOOR BOILERS

Measured in inches of water at third pass, for loads from zero to 200% rating; *A* for 604 HP., *B* for 524 HP., and *C* for 260 HP. B. & W boilers, oil burning; *D* for cross-baffled 3-pass Edge Moor boiler with coal.

FLUE PROPORTIONS

Flues should be designed with reference to the total volume of furnace gases which they are to handle, rather than according to the grate area.

The friction loss of draft in conduits (stacks, flues and breechings) can be computed by the following formula, from *Steam*, or Fig. B, page 213, can be used.

$$d = \frac{sW^2PHT}{A^3},$$

$d =$ draft loss, in. water column.
$W =$ weight of gases, lb. per sec.,
$P =$ perimeter of conduit, ft.,
$H =$ length of conduit, ft.,
$s =$ a factor, with the following values at sea level:
.00000138 for circular steel conduit,
.00000187 for brick or brick lined conduit,
$A =$ cross-sectional area of conduit, sq. ft.,
$T =$ absolute temperature of gases, ° F.

The breeching should be of such a size that the velocity of gas flow will not exceed 35 ft. per second. Experience has shown that a circular section gives less draft loss than a square or rectangular section. The retarding effect of a square flue is 12% greater than that of a circular one of equal area. The retarding effect of a 1 : 1½ rectangular flue is 15% greater.

The loss of draft in bends can be calculated from the following formula:

$$d_1 = b \frac{W^2T}{A_1{}^2}$$

where $d_1 =$ draft loss, in. water column,
$A_1 =$ cross section of flue, sq. ft.,
$W =$ lb. per sec. of gases,
$T =$ absolute temperature of gases, ° F.,

b = coefficient depending on bend.
  = .0000803 for right angle sharp bend
   .0000219 sharp 135° angle (ι. e, deflection of 45°)
   .0000182 right angle bend, radius equal diameter of pipe
   .0000110   "   "   "   "   " 2 to 4 diams. of pipe
   .0000051   "   "   "   "   " 5 to 6 diams of pipe
   0   "   "   "   "   " more than 6 diams. of pipe
   .0000110 135° Y branch
   .000073 $[(A_2/A_1)-1]^2$ for sudden changes in cross section

A_2 = cross section of large pipe, A_1 = cross section of small pipe.

Menzin says one sharp right angle bend has the same friction as 50 ft. of length.

The draft required by an economizer of the *Green* type, having vertical pipes of about 4½ in. diameter and spaced 8 in. center to center in the section and on 7¼ in. centers, section to section, can be determined from.

$$d_2 = \frac{6.606}{10^{12}} F^2 L\, T$$

wherein d_2 = draft, in. water col,
   F = flow of gases in lb. per hr. divided by the number of lineal ft.
        of pipe in each economizer section,
   L = number of economizer sections,
   T = mean absolute temperature of the gases, ° F.

The relation between draft expressed in feet head of gas (H), the volume of flow (S) in cu. ft. per sec, and the resistance (R) of the conduit is

$$H = RS^2$$

The unit of R is the resistance through which 1 ft. head will force 1 cu ft. **per sec.** and is the resistance of a circular orifice of 0.498 ft. diameter **(0.189 sq. ft. area)** in a thin plate A stream moving with the velocity due **to H, and** passing 1 cu. ft. per sec. would occupy a cross section of only **0.653 × 0.189 sq. ft.,** in other words the coefficient of a thin-plate circular **orifice is 0.653.** An orifice with a raised edge or collar on the up-stream **side has** a coefficient of about 0.5, if the collar is on the discharge side the **coefficient is** about 0.83, while if the entrance to the end of a suction pipe **(as of a fan)** is bell mouthed, the coefficient is nearly unity, that is, the **only head** required to create flow into such a pipe is that corresponding to **the velocity** in the full section of the pipe; there is no entrance loss. The **resistance** of similar orifices varies as $1/A^2$, where A is the area of the **orifice.** The resistance of a circuit containing resistances in series, as of **fire bed,** boiler, flues and chimney, is the sum of the individual resistances. **The resistance** of a circuit containing several resistances in parallel, as of **a number** of boiler settings discharging into a common smoke flue, is found **from the equation**

$$\frac{1}{\sqrt{R}} = \frac{1}{\sqrt{R_1}} + \frac{1}{\sqrt{R_2}} + \text{etc.}$$

Where R is the resistance of the circuit as a whole, and R_1, R_2, etc., are the resistances of the individual parts arranged in parallel.

Lbs of Water evaporated from and at 212 ft per lb of Fuel or Combustible
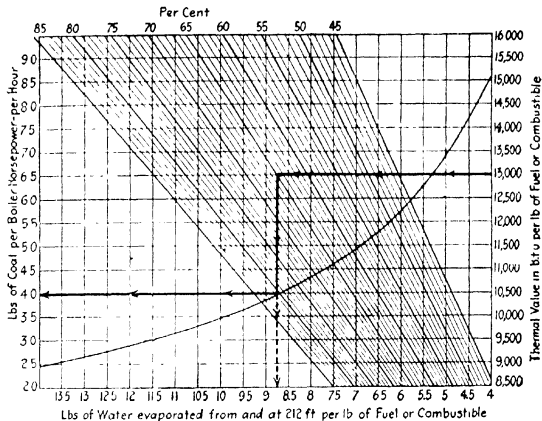
A POUNDS OF COAL PER BOILER HORSEPOWER FOR DIFFERENT HEAT
   VALUES AND EFFICIENCIES, FOR FIXING GAS PASSAGE AREA
                                                        --Power

W. C. Stripe gives a graphical method for areas of gas passages. The
factors to be considered are boiler HP. developed, lb. coal per boiler
HP. hr., lb air theoretically required per lb coal, % of theoretical air
actually used, temperature and velocity of gases at the point considered.
The use of the charts can best be illustrated by an example.

Assume 1500 boiler HP., coal of 13,000 *BTU* heating value, combined
boiler and furnace efficiency 65%, air supply 175% of the theoretical, tem-
perature of the gases at the point to be considered 1000° F., velocity of
gases 35 ft. per sec. The curve in *A* determines the coal per boiler HP. hr.
Follow the 13,000 *BTU* horizontal until it intersects the 65% efficiency
diagonal, drop vertically to the curved line, follow horizontally to the left-
hand scale, 4 lb. of coal is required per boiler HP. hr. Incidentally the
equivalent evaporation can be determined as indicated   Turning to Fig. B,
locate 1500 HP. on scale A, project vertically to the 4-lb. coal oblique
line, horizontally to the left to the 13,000 *BTU* diagonal line, downward to
100% diagonal, horizontally to the left to the 175% diagonal, vertically
downward to the 1000° diagonal, then to the right to 35 ft. per sec
velocity, and vertically upward to the scale *F*, where 30 sq. ft. is determined
as the approximate effective area for the particular gas passage.

Partial results may be obtained from any of the intermediate scales *B*,
C, *D* and *E*.

Osborn Monnett made the following recommendations to the Standards
Committee of the Smoke Prevention Association:

Breechings should be as short and direct as possible, preferably
having a direct run, without turns, into the stack. No right-angle turns
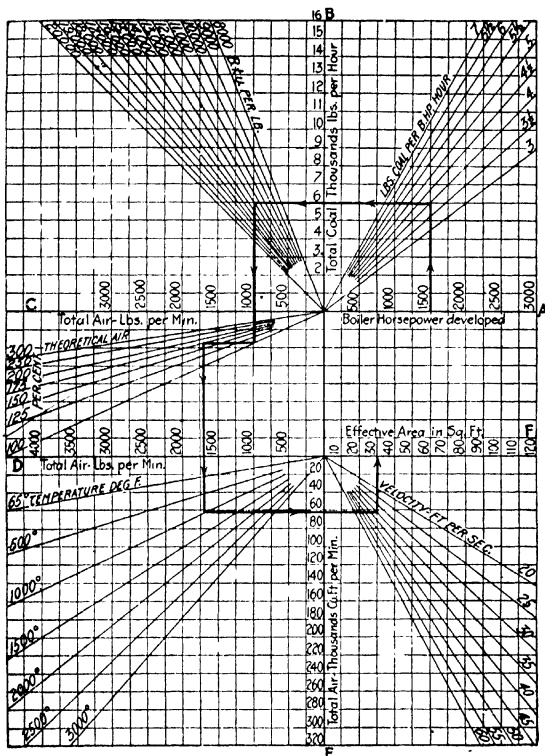
B. CHART FOR DETERMINING THE EFFECTIVE AREA OF GAS PASSAGES
—Power.

should be used. If turns are necessary, they should be long-sweep bends with a radius on the center of the turn of not less than the diameter or width of the breeching. The breeching should not dip below the horizontal, but should slope upward to the stack. The connection to the stack should preferably be at an angle of 45°. Breechings should not be constructed of brick or other porous material subject to leakage. Breechings of steel plate should have reinforcing angle irons on the outside, and no projections on the inside to resist the flow of the gases. Lagging should be on the outside, where its condition can readily be inspected, where repairs can be

made without interrupting the operation of the plant and where loose pieces will not obstruct the flow of the gases. Clean-out doors should be provided at convenient points for the removal of accumulations of soot.

For water-tube boilers the area of the breeching should not be less than 22% of the total area of the grate surface served, or a ratio of breeching to grate surface of 1 to 4½. For horizontal return-tubular boilers the area of the breeching should be 25% in excess of the total area through the tubes. Breechings should preferably have a circular or square section. In case of rectangular shape, one side should not be more than one-third greater than the other.

Steam recommends that flue areas should preferably be 20% larger than the stack. A safe rule is to allow 35 sq. ft. for 1000 HP. Proportion the areas of different parts of the flue to the volume of gases to pass through it. For circular steel flues of about the same size as stack, or flues reduced proportionately to the volume of gases, a convenient rule is to allow 0.1 in. draft loss for 100 ft., and 0 05 in. loss for each right-angle turn This holds good for square and rectangular flues. For brick or concrete flues, double the figures.

STACK PROPORTIONS

The proper height and diameter of a stack depend upon
1. The amount of fuel to be burned,
2. Its nature,
3. The temperature of the gases,
4. The grate area,
5 The design of the flues,
6 The arrangement of the flues relative to the boilers,
7. The altitude of the plant.

The amount of fuel to be burned determines the quantity of gases, while the temperature and altitude determine the volume of this quantity of gases. 1, 3 and 7 must therefore be considered in determining the diameter. The amount of fuel, its nature, the grate area and the design of flues and gas passages determine the draft intensity required. The stack height and the gas temperature determine the draft intensity available.

A method for proportioning stacks on a **gas basis** is described by *A. L. Menzin:* The draft available at the boiler damper must be sufficient to give the gases velocity head (P_v), overcome the fuel bed loss (P_z) and the boiler loss (P_b). It is also the theoretical draft produced by the stack (P_s) less the friction loss in the stack (P_c), the friction loss in the breeching (P_r) and the damper friction (P_d). Expressed as a formula:

$$P_z + P_b + P_v = P_s - P_c - P_r - P_d, \text{ or}$$
$$P_s = (P_z + P_b + P_v) + P_r + P_d + P_c$$

wherein P_z = draft loss through fuel bed
P_b = draft loss through the boiler
P_v = draft required to produce velocity
P_s = theoretical draft produced by the stack
P_c = friction draft loss in the stack
P_r = friction draft loss in the breeching
P_d = friction draft loss at damper, which can be considered zero for a well-designed damper wide open.

The determination of the area of the stack and the velocity requires an estimate of the volume of gases.

Since the proportion of oxidizable matter per lb. of different fuels varies between very wide limits, the minimum amount of air required per lb. of fuel for complete combustion varies accordingly. The air per lb. of combustible is less variable The air per BTU is almost constant For several samples of lignite, bituminous and semi-bituminous coals, anthracite and California crude oil, the calculated *minimum* moisture-free air per 10,000 BTU by the bomb calorimeter did not vary more than $1\frac{1}{2}\%$ from $7\frac{1}{2}$ lb. The BTU basis is therefore adopted for determining the quantity of gases equivalent to a given boiler HP.

On this basis the *weight* of gas per HP.-hr. is approximately:—

$$W = \frac{33,480\,w}{10,000\,(E + .02)}$$

W = weight of gas in lb per hr per boiler HP,
w = weight of gas per 10,000 BTU,
E = combined efficiency of the steam generator expressed as a fraction,

.02 is added to E as an average for carbon in the ash. E and the corresponding % of CO_2 must be assumed low enough to take care of unusually poor operating.

The quantity w can also be determined from the anticipated CO_2 percentage, by the third line in the following table, which includes a number of other functions of the CO_2 percentage.

WEIGHT OF GASES AND PERCENTAGE OF HEAT REJECTED TO THE CHIMNEY FOR DIFFERENT PERCENTAGES OF CO_2 WHEN $CO = 0$

—*Menzin*

% CO_2 in the Dry Gases by Volume	18 7	18 0	17 0	16 0	15 0	14 0	13 0	12.0
Excess air in % of the theoretical minimum	0	4	10	17	24	33	43	54
Weight of gases per 10 000 BTU in the coal lb	7 8	8 1	8 6	9 1	9 6	10 3	11 0	11 9
Chimney loss per 100° Fahr. in % of the cal-orific value of the coal	1 85	1 92	2 04	2 16	2 28	2 44	2 61	2 82
Chimney loss per 500° Fahr.	9 25	9 60	10 20	10 80	11 40	12 20	13 05	14 10
% CO_2 in the Dry Gases by Volume	11 0	10 0	9 0	8 0	7 0	6 0	5 0	
Excess air in % of the theoretical minimum	68	85	105	130	162	206	267	
Weight of gases per 10,000 BTU in the coal, lb	12 9	14 2	15 7	17 6	20 0	23.3	27.8	
Chimney loss per 100° Fahr. in % of the calorific value of the coal	3 06	3.37	3 72	4 17	4 74	5.52	6 59	
Chimney loss per 500° Fahr.	15.30	16 85	18.60	20 85	23.70	27.60	32 95	

The *volume* of gas per HP.-hr. is approximately:—

$$q = \frac{30WT}{41.3\,P \times 3600} = \frac{201.9WT}{10^6\,P}$$

q = volume of gas in cu. ft. per sec. per boiler HP.
W = weight of gas in lb. per hr. per boiler HP., as above.
P = barometric pressure in inches of mercury.
T = temperature of the gases in ° F. absolute.

In ordinary problems the table below can be used instead of computing the weight or volume of gases.

WEIGHT AND VOLUME OF GAS PER BOILER HP AT SEA LEVEL

Assumed CO_2 % of dry gases by volume	8	8	9	10	12	12	14	14
Assumed combined efficiency of boiler, grate and furnace	63	66	66	68	70	75	68	78
Weight of gases in lb per hr per boiler HP	91	87	77	68	55	52	49	43
Volume of gases in cu ft per sec per boiler HP for a temperature of 540° F and 30 in mercury	61	58	52	46	37	35	33	.29
Suggested corresponding percentage of rated capacity of boiler to be used for proportioning chimneys	100	125	150		200		250	...

Another method of determining the volume of gases is to assume the weight of coal to be burned per HP and the probable excess air and make use of Figure A, p 213, giving the volume of gases per pound of combustible approximately, but sufficiently accurately for computations. This is redrawn after G. Herberg. The approximation assumes that the heat value is due entirely to carbon and that the ratio of air supplied to air required is the ratio of the maximum CO_2 percentage possible to the actual CO_2 percentage. See pages 275 and 594.

Having determined the quantity of gas per boiler HP, either by computation or the table, determine the total gases to be handled, i. e. assume the average CO_2 percentage expected and use the suggested percentage of rated capacity in the table

ASSUMED ECONOMICAL VELOCITIES FOR A FIRST APPROXIMATION

Volume of gas to be removed in

cu. ft per sec	....	....	10	50	150	500	1200	2500	5000	8000
Economical velocity, ft. per sec.	10	15	20	25	30	35	40	45

Having determined the gas volume, assume a velocity from the above, and calculate the stack areas corresponding to several velocities above and below this figure. The area of a conduit is the total volume of gases handled divided by the velocity. See page 207 for a graphical method of determining area of gas passages.

Referring to the formula on page 209

$$P_x = (P_g + P_b + P_v) + P_i + P_a + P_c$$

The draft through the fuel bed (P_g) can be determined as on page 201. If forced draft is used for the fuel bed, as in stoker installations, the stack does not have to take care of this item

The draft through the boiler (P_b) can be estimated, as on page 203. Menzin uses the curve on page 204, as sufficiently accurate, since condition of equipment must be assumed.

The draft to produce velocity (P_v),

$$= 0.123 \frac{P\ (v_2{}^2 - v_1{}^2)}{30\ T}$$

$P =$ barometric pressure in ins. Hg.
$v_1 =$ initial velocity of gases in ft. per sec,
$v_2 =$ final velocity of gases in ft. per sec.,
$T =$ temperature of gases ° F. abs. ($= °$ F. $+ 460$)

This is usually small. v_1 is zero, since the air is practically stationary in the ash-pit. v_2 can be assumed as in table above.

The sum of these three, P_g, P_b and P_v, is the draft required at the damper.

The friction draft loss in the breeching or chimney, according to *Menzin*, is

$$P_r \text{ or } P_c = F \frac{l}{d} \left(\frac{v_2}{T} \right) \text{ in in. water.}$$

F = coefficient = .008,
d = diameter in ft.,
l = length in ft.,
v = velocity in ft. per sec.,
T = abs. temperature of gases in ° F.

The length of the breeching must include bends, etc. (See page 205.) Curve B, page 213, can be used to obtain the frictional loss of draft in the flues and stacks of the diameters corresponding to the assumed velocities.

The breeching loss must also include the loss due to sudden enlargements of gas passage, P_e.

$$P_e = \frac{0.123 \, P \, (v_1^2 - v_2^2)}{30 \, T} \text{ wherein}$$

P_e = draft loss in in. of water, P = barometric pressure in in. of mercury, v_1 and v_2 = velocities in ft. per sec., T = temperature in ° F. abs.

P_d, the damper draft loss, can be neglected, P_c, the friction loss in the stack itself, is a function of its height. It can be calculated as above, or Fig. B, by *Menzin*, can be used.

P_s, the theoretical draft which the stack will supply, is related to the flue and air temperatures as shown in Fig. C, and the height must be chosen so as to make P_s equal the sum of the draft losses.

The draft theoretically produced by a stack is that due to the difference in weight between a column of gas of its height and average temperature and that of a corresponding column of outside air. Friction losses are negligible at low velocities, but the cross section must be kept small for reasons of economy, which results in comparatively high velocities and appreciable friction loss. In practice the cross section must be as small as possible without destroying the advantage created by the height.

Steam gives the following for determining the **theoretical draft** due to a given stack height:—

$$P_s = 0.255 \, P \, H \left(\frac{1}{T_a} - \frac{1}{T_c} \right)$$

P_s = draft in in. of water,
H = height of stack above the grate bars in ft.,
P = atmospheric pressure in in. mercury,
T_a = absolute temperature of the atmosphere ($60 + 460 = 520°$ F. average conditions),
T_c = absolute temperature of the stack gases.

The formula assumes that the stack gases have the same density as air. The error due to this is negligible, as a correction factor is applied in practice. The figures obtained by this formula should be corrected to allow for friction loss in the stack, usually about 25% of the draft.
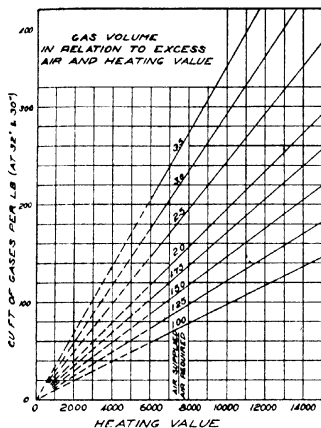
A. FLUE GAS VOLUME AS FUNCTION OF HEATING VALUE OF COAL AND EXCESS AIR USED
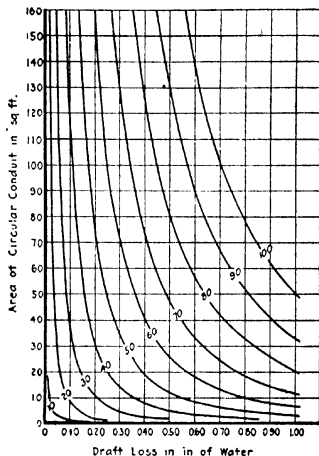
B. DRAFT LOSS PER 100 FT. OF A CIRCULAR BRICK-LINED CONDUIT CORRESPONDING TO THE VELOCITIES IN FT. PER SEC. NOTED ON THE CURVES.

For barometer at 30-in. mercury and gases at 540° F. For any other height or length H in ft., multiply by 0.01 H. For a square conduit of side equal to the diameter of a circular conduit. multiply by 0.62. For any other barometric pressure P in inches of mercury, multiply by 30/P. For any other gas temperature t in ° F., multiply by 0.001 $(t + 460)$.—$A.$ $L.$ $Menzin.$
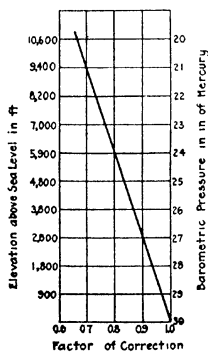
C. MAXIMUM DRAFT AT SEA LEVEL PER 100 FT. OF CHIMNEY HEIGHT CORRESPONDING TO AIR TEMPERATURES ON THE CURVES. For any other height H in ft. multiply by 0.01 H. For any other altitude or barometric pressure, multiply by the corresponding factor of correction from the curve on the right.— $A.$ $L.$ $Menzin.$
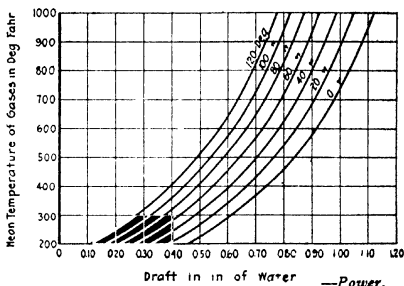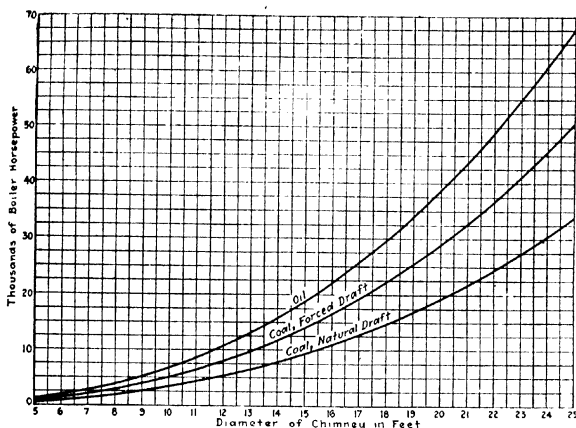
1. APPROXIMATE WORKING CAPACITY OF CHIMNEYS BASED ON
   BOILER HP., ATMOSPHERE AT 60° F, SEA LEVEL
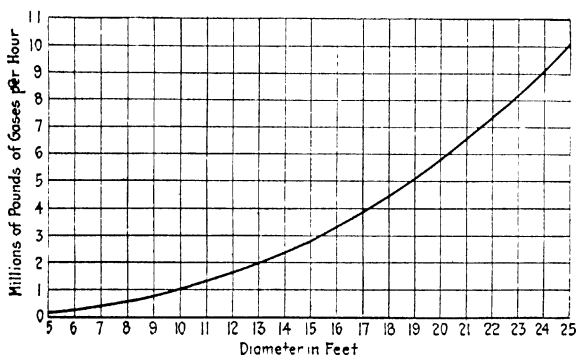
2. MAXIMUM GAS CAPACITY OF CHIMNEYS, ATMOSPHERE AT 60° F.,
   SEA LEVEL—*A.S.M.E.*

Alfred Cotton developed a method of chimney design based on *Menzin's* study of frictional resistance and on his own work on mean chimney temperatures, and gave the following example of its application. A central power station is to have boilers in groups of four to each chimney, each boiler 1400 HP. rating, 14 tubes high, to carry peak loads of 300%. Forced-draft underfeed stokers to be used, 30% excess air assumed,

Temperature of Chimney Gases, Deg. Fahr
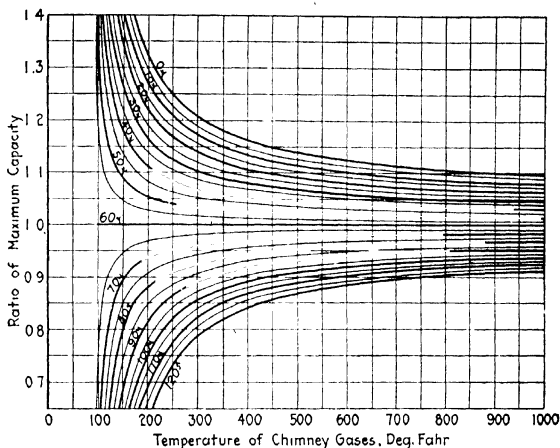
3 RELATION OF MAXIMUM CAPACITIES WITH ATMOSPHERE AT TEMPERATURES MARKED ON CURVES TO THAT WITH ATMOSPHERE AT 60° F.—A S M E.

temperature of gases entering stack predicted as 640° F. Fig. 1 gives, as a first approximation, 16 ft. as the diameter of a stack to handle 16,800 boiler HP. Diameters from 13 to 19 ft. are listed in Column 1, p. 217, corresponding maximum gas capacities in lb per hr in Column 2. The maximum capacity, *for a given mean gas temperature*, depends on diameter only, and can be taken from Fig. 2, for mean gas temperatures from 375° to 1135° F., and atmosphere at 60° F. For mean gas temperatures below 375° F., a more elaborate chart is required, while for atmospheric temperatures different from 60° F., the maximum capacity is corrected by multiplying by a ratio from Fig. 3. The weight of gases is calculated from the coal analysis, etc., and is 858,000 lb. per hr. for the Pennsylvania bituminous coal used. Column 3 is Column 2 divided by 858,000. Column 4 is the fraction of the total static draft which is available after deducting friction for moving the stated fraction of the maximum capacity for gas, and equals 1 00 — (Column 3)². The draft loss through the boiler is ascertained from the maker to be 1.3 in. of water for 300% of rating, that through the fuel bed is read from Figure 4, as 0.1 in., and that through the flues, at 0.1 in. per 100 ft., and 0.05 in. for each 90° turn, is 0.15 in.; the total, 1.55 in., is divided by Column 4 to give Column 5, and an assumed 0.1 in. for gas acceleration is added to give Column 6, the first approximation for static draft to be provided in the chimney. From Fig. 5 the static draft at assumed mean gas temperature 550° F. is found to be 0.675 in. per 100 ft. of stack, from which the approximate heights in Column 7 are calculated, corresponding to the drafts in Column 6. From Fig. 6 and the diameters and heights in Columns 1 and 7, a % temperature correction
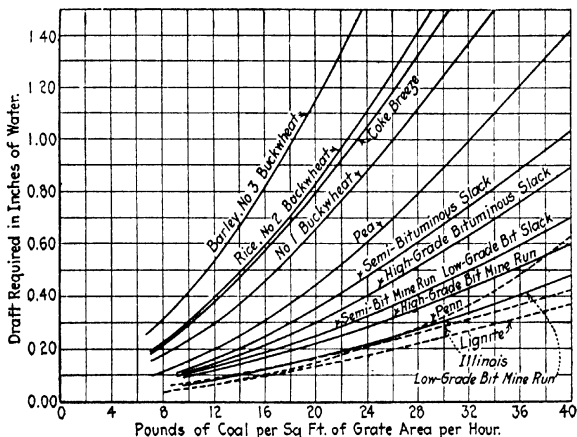
4. DRAFT LOSS THROUGH FUEL BED WITH DIFFERENT FUELS. (Broken-
line curves are for chain grates, by *Green Engineering Co.*)
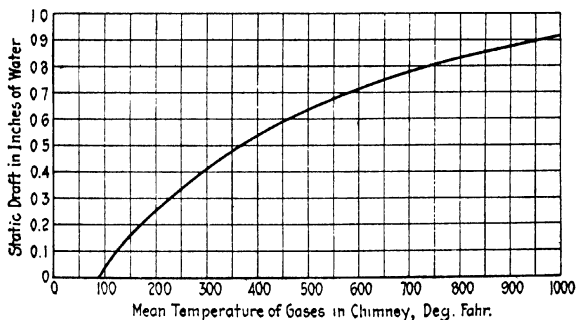
5. STATIC DRAFT PER 100 FT. OF STACK, ATMOSPHERE AT 60° F.
—*A.S.M.E.*

factor, Column 8, is read, this is multiplied by the excess of temperature
of gases entering stack above atmospheric (640° F. — 60° F.) to give Column
9, and 60° F. added to give Column 10, the mean gas temperature in the
chimney. From this temperature and the diameter, Fig. 7 gives Column 11,
the draft loss to give acceleration to the gases at maximum capacity.

COTTON'S METHOD OF CHIMNEY STUDY

6. FACTORS FOR FINDING MEAN GAS TEMPERATURE IN CHIMNEYS

Chart: Percentage of Entering Temp. Diff. (vertical axis, 100–60) versus Height of Chimney in Feet (horizontal axis, 40–400); curves labeled "20 Feet Diameter."

(1) Diameter in feet	(2) Maximum capacity as in Fig. 2	(3) Working capacity = fraction of maximum capacity	(4) Draft required, fraction of static draft	(5) Draft required, 1.55 in — col. (4)	(6) Static draft required = col. (5) + 0.1 for gas acceleration	(7) Height with mean temperature at 550 deg fahr.	(8) Factor for mean temperature	(9) Mean temperature difference	(10) Mean temperature of chimney gases	(11) Draft loss by gas acceleration at maximum capacity	(12) Fraction of gas acceleration at working capacity	(13) Gas acceleration at working capacity	(14) Total static draft required	(15) Height required at mean temperatures of col. (10)	(16) Product of height by diameter
13	2 000,000	0.429	0.815	1.902	2.002	297	0.795	461	521	1.30	0.183	0.238	2.140	327	4251
14	2,380 000	0.360	0.870	1.782	1.882	280	0.805	467	527	1.40	0.130	0.182	1.964	300	4200
15	2,820 000	0.304	0.908	1.707	1.807	268	0.815	473	533	1.51	0.092	0.139	1.846	280	4200
16	3,320,000	0.258	0.932	1.663	1.763	261	0.824	478	538	1.62	0.066	0.107	1.770	266	4256
17	3,860,000	0.222	0.950	1.632	1.732	257	0.833	483	543	1.73	0.049	0.085	1.717	256	4352
18	4,450,000	0.193	0.962	1.611	1.711	253	0.841	488	548	1.84	0.037	0.068	1.679	249	4482
19	5,090,000	0.169	0.971	1.596	1.696	251	0.849	492	552	1.95	0.028	0.055	1.651	245	4655

7. DRAFT LOSS DUE TO ACCELERATION OF GASES, MAXIMUM CAPACITY, MEAN GAS TEMPERATURES AS ON CURVES, SEA LEVEL

Column 12 is (Column 3)^2, while Column 13 is Column 11 $\times$ Column 12, and represents the actual draft loss to give acceleration to the gases. This, added to Column 5, gives Column 14, a more accurate figure for the static draft required than is Column 6. Column 15 is a revised estimate of heights to give said static drafts, determined in the same manner as Column 7. If Column 10 is refigured for these heights, the difference is found to be only one or two degrees, so Columns 1 and 15 can be used as giving a set of appropriate diameters and heights, and as the cost of chimneys varies approximately with the product of height and diameter, plotting the values in Column 16 shows that the optimum dimensions are 14½ ft. diameter and 289 ft. height.

H. M. *Brayton* calls attention to the fact that the **cooling of the gases** as they ascend a chimney does not proceed in a linear relation, and that therefore the draft produced, which is a function of the difference of temperature between the gases and the outside air, is not strictly proportional to height. In a test on a 250-ft. chimney of the Boston Edison Co., the absolute temperature T at various points in the chimney height H was found to vary according to $TH^{0.04} = 1000$. From a similar relation the *average* temperature of a chimney of any proposed height can be determined, and the draft figured for different heights. This is quite a laborious process, but the results obtained by this method are embodied in Fig. A, which gives the drafts corresponding to various heights and flue temperatures, for an outside temperature of 70° F. Each 10° variation in external air causes about 3% variation in draft.
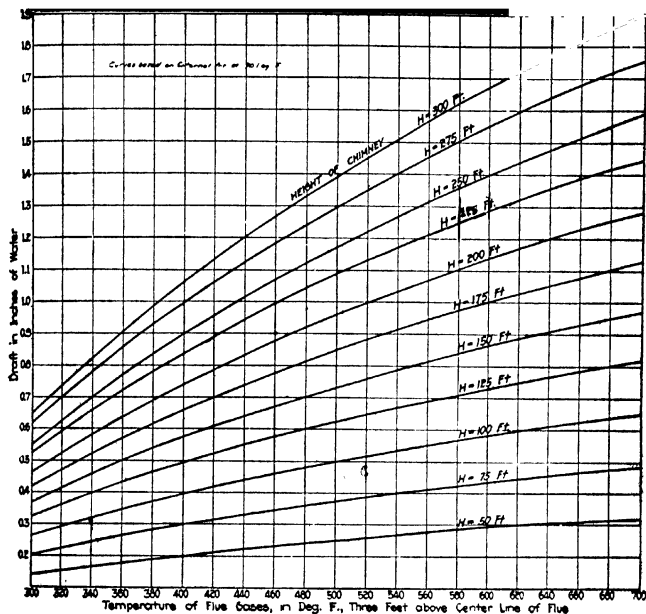
A. RELATION OF DRAFT, FLUE TEMPERATURE AND CHIMNEY HEIGHT, EXTERNAL AIR AT 70° F. —*Power.*

Julian C. Smallwood has conducted experiments to determine the temperature variations in a 150-ft. hexagonal brick chimney 8 ft. across outside section at bottom, serving boilers rated at 1000 HP., at the Johns Hopkins University, the results of which are shown in Fig. B. The observed differences in pressure at the top and bottom, and the calculated drafts due to the temperatures, are given in the following table, also the value of the constant c in the formula $TH^{0.04} = c$.

	A	B	C	D
Temperature at breeching, ° F........	464	390	277	249
Exit temperature	328	270	206	173
Average temperatures	357	310	221	190
Observed pressure difference........	0.734	0.665	0.470	0.500
Calculated draft	0.752	0.685	0.492	0.504
Value of c..........................	955	890	795	760

These experiments demonstrate the high degree of cooling during the 15 to 25 seconds in which the gases traversed the stack, the average
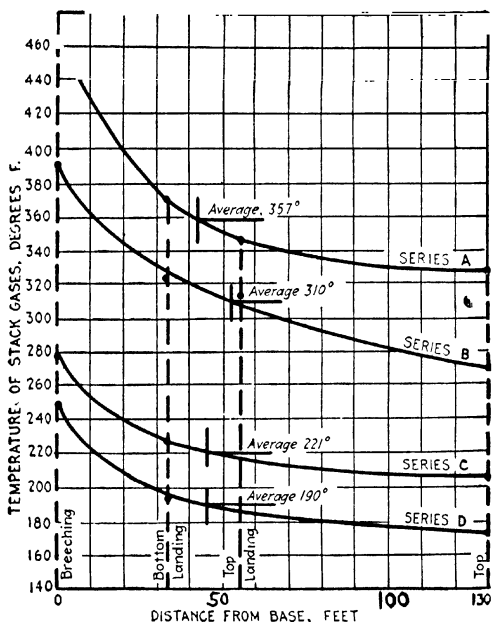
B. TEMPERATURE VARIATION IN 150 FT. CHIMNEY
—Power.

temperature being decidedly less than the breeching temperature, and much below the median temperature even. This suggests the fact that with high chimneys the cooling may become so pronounced and the friction losses so great that the upper portions actually reduce the available draft. The low stack temperatures also illustrate the reduction in draft by reason of inleakage through idle boilers.

APPROXIMATE DETERMINATION OF STACK PROPORTIONS

Since the complete determination as outlined above may not be desired the following tables and data are included.

Fig. C embodies suggested combinations of height and diameter of stack for use with boilers rated as indicated, based on *Kent's Chimney Formula:*

HP. $= 3.33 \ (A - 0.6 \sqrt{A}) \ \sqrt{H}$

$A =$ cross section in sq. ft.

$H =$ height in ft.

C. STACK SIZES BY KENT'S FORMULA
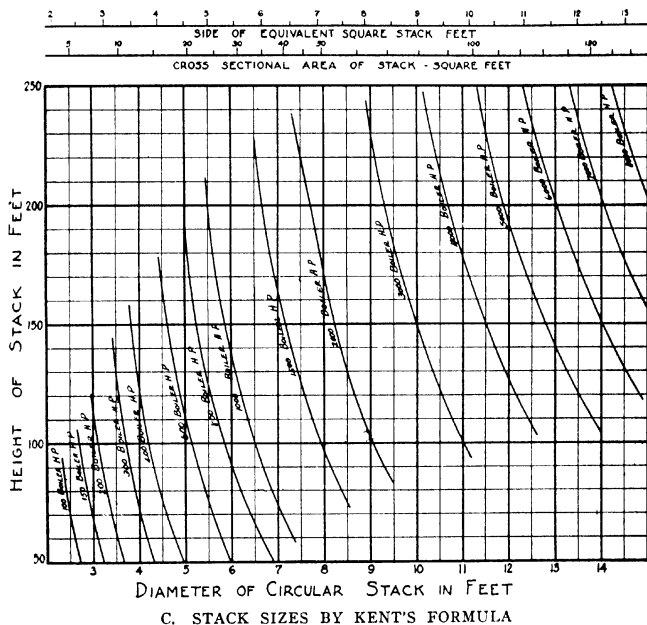
This is developed on the assumption that the capacity of the chimney varies as the effective area and the square root of the height and that the effect of friction is equivalent to a lining of inert gas 2 in. thick.

It allows for approximately 5 lb. of coal per HP.-hour, and is satisfactory for ordinary rates of combustion for bituminous coals. When low-grade Western bituminous coals are used, it is advisable to increase the size 25 to 60%.

Fig. D, from *Steam*, is based on the formula, Diam. in in. $= 4.68$ $(HP.)^{2/5}$, where HP. is horsepower for 100 ft. height. For brick-lined stacks add 6% to the diameter.

COCHRANE CORPORATION

The table below, from *Steam*, indicates the range of drafts which can be secured from stacks of a given size when connected to boilers of various ratings above and below those for which they are most suitable.

AVAILABLE DRAFT CALCULATED FOR 100-FT. STACK OF DIFFERENT DIAMETERS, ASSUMING STACK TEMPERATURE OF 500° F. AND 100 LB. OF GAS PER HP. FOR OTHER HEIGHTS OF STACK MULTIPLY BY HEIGHT/100.

Horse Power	Diameter of Stack in Inches														
	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120
100	.64														
200	.55	.62													
300	.41	.55	.61												
400	.21	.46	.56	.61											
500		.34	.50	.57	.61										
600		.19	.42	.53	.59										
700			.34	.48	.56	.60	.63								
800			.23	.43	.52	.58	.61	.63							
900				.36	.49	.56	.60	.62	.64						
1000				.29	.45	.53	.58	.61	.63	.64					
1100					.40	.50	.56	.60	.62	.63	.64				
1200					.35	.47	.54	.58	.61	.63	.64	.65			
1300					.29	.44	.52	.57	.60	.62	.63	.64	.65		
1400						.40	.49	.55	.59	.61	.63	.64	.65		
1500						.36	.47	.53	.58	.60	.62	.63	.64	.65	.65
1600						.31	.43	.52	.56	.59	.62	.63	.64	.65	.65
1700							.41	.50	.55	.58	.61	.62	.64	.64	.65
1800							.37	.47	.54	.57	.60	.62	.63	.64	.65
1900							.34	.45	.52	.56	.59	.61	.63	.64	.64
2000								.43	.50	.55	.59	.61	.62	.63	.64
2100								.40	.49	.54	.58	.60	.62	.63	.64
2200								.38	.47	.53	.57	.59	.61	.62	.64
2300								.35	.45	.52	.56	.59	.61	.62	.63
2400								.32	.43	.50	.55	.58	.60	.62	.63
2500									.41	.49	.54	.57	.60	.61	.63

Horse Power	Diameter of Stack in Inches							
	90	96	102	108	114	120	132	144
2600	.47	.53	.56	.59	.61	.62	.64	.65
2700	.45	.52	.55	.58	.60	.62	.64	.65
2800	.44	.50	.55	.58	.60	.61	.64	.65
2900	.42	.49	.54	.57	.59	.61	.63	.65
3000	.40	.48	.53	.56	.59	.61	.63	.64
3100	.38	.47	.52	.56	.58	.60	.63	.64
3200		.45	.51	.55	.58	.60	.63	.64
3300		.44	.50	.54	.57	.59	.62	.64
3400		.42	.49	.53	.56	.59	.62	.64
3500		.40	.48	.52	.56	.58	.62	.64
3600			.47	.52	.55	.58	.61	.63
3700			.45	.51	.55	.57	.61	.63
3800			.44	.50	.54	.57	.61	.63
3900			.43	.49	.53	.56	.60	.63
4000			.42	.48	.52	.56	.60	.62
4100			.40	.47	.52	.55	.60	.62
4200			.39	.46	.51	.55	.59	.62
4300				.45	.50	.54	.59	.62
4400				.44	.49	.53	.59	.62
4500				.43	.49	.53	.58	.61
4600				.42	.48	.52	.58	.61
4700				.41	.47	.51	.57	.61
4800				.40	.46	.51	.57	.60
4900					.45	.50	.57	.60
5000					.44	.49	.56	.60

FOR OTHER STACK TEMPERATURES ADD OR DEDUCT BEFORE MULTIPLYING BY HEIGHT – 100 AS FOLLOWS*

For 750 Degrees F. Add .17 inch	For 650 Degrees F. Add 11 inch	For 550 Degrees F. Add .04 inch.	For 400 Degrees F. Deduct .09 inch.
For 700 Degrees F. Add .14 inch.	For 600 Degrees F. Add 08 inch	For 450 Degrees F. Deduct 04 inch	For 350 Degrees F. Deduct 14 inch.

The following remarks about draft and chimney heights are due to E. A. Uehling: The intensity of draft produced by a given chimney increases with the gas temperature. All useless loss of temperature, such as radiation from the uptake and flues and leakage of cold air into the flues and chimneys, must be avoided. Natural draft is greatly affected by atmospheric conditions. Barometric pressure, temperature and humidity all have their effects upon the draft from a given chimney. Chimneys at high altitudes must be higher and larger than at sea level because of the lower barometric pressure and the lower density of the air. Even at sea level
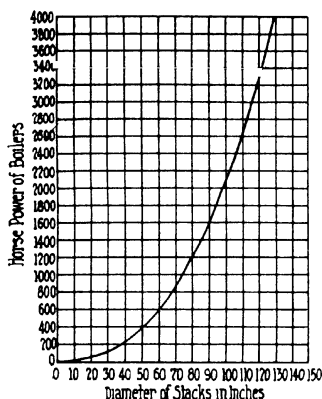
D. CAPACITY OF 100-FT. STACKS
—*Steam.*
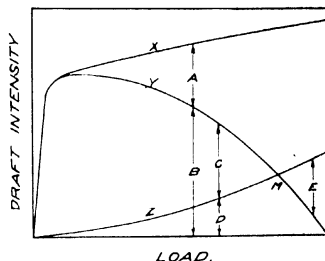
E. DRAFT RELATIONS WITH CHIMNEY DRAFT

the barometric pressure may vary from 28 to 31 in., which produces a variation of 9.68% in the effectiveness of the draft. Since natural draft depends primarily on the difference in temperature between the gas inside and outside the chimney, it will be affected as much by changes of temperature outside as by changes in the temperature of the gas in the chimney. Assuming a uniform stack temperature of 500° F., a chimney would show 41% greater draft with an atmospheric temperature of 20° below zero than with an atmospheric temperature of 100° above. Draft is better in clear, dry weather than in hot, sultry or foggy weather. This is due to a lower barometric pressure in the latter case, and to the fact that the water vapor which displaces air weighs less than air and a large volume of air is required for given combustion conditions. Besides displacing air, the water vapor absorbs heat and retards combustion in the fuel bed. The effect of a brisk wind in the right direction is well known, although its influence cannot be even approximately calculated. The variations in the atmosphere rarely occur to the full extent and probably never at the same time, and one condition may neutralize largely the effects of the others.

The above Fig. E, adapted from *M. Gensch,* illustrates draft relations as they affect the power capacity of a chimney. The upper curve represents the theoretical draft which a given stack would give at different loads. The draft is proportional to the product of the height and the difference of the reciprocals of the air temperature and the stack gas temperature in absolute degrees. The pressure A required to overcome the resistance of the boiler, flues and stack is proportional to the square of the load. The middle curve Y was obtained by subtracting values proportional to the square of the load from the upper curve. It therefore represents the draft B available for overcoming the fuel bed resistance. The lower curve Z represents the draft D required by the fuel bed at the different loads. When the middle curve is above the lower one there is excess draft and

the damper must be partially closed, to use up by its resistance the draft represented by the distance C between the two curves. At load M the draft for the fuel bed is just sufficient for its requirements and the damper should be wide open so that it offers no resistance. The draft available for the fuel bed is not sufficient to increase the load beyond this point, and a mechanical draft arrangement must make up the difference represented by the distance E between the two curves.

The *Stoker Manufacturers Association* recommends the chimney sizes given in the accompanying tables. Using Table I., the stack diameter is determined from the boiler heating surface and the rate of driving, while in Table II. the height is determined from the rating and the total draft loss through furnace, boiler and breeching. The assumptions on which they are based are indicated at the foot of each table.

I. STACK TABLES, DIAMETER OF CHIMNEY IN INCHES

Computed for Brick Chimneys at Sea Level for a Friction Loss of One-Tenth Inch of Water Per 100 Ft of Height

Sq. Ft. of Boiler Heating Surface	Rated Boiler HP.	% of Boiler Rating				
		100	150	200	250	300
500	50	21	24	27	29	31
1,000	100	24	32	34	36	41
1,500	150	31	36	41	45	48
2,000	200	36	42	45	52	55
2,500	250	38	44	48	55	60
3,000	300	41	48	53	58	64
4,000	400	48	54	61	67	72
5 000	500	53	60	68	74	80
6.000	600	55	65	72	77	86
7,000	700	62	69	78	84	92
8,000	800	65	74	82	89	98
9.000	900	67	78	85	93	103
10,000	1,000	72	81	91	98	106
12,000	1,200	74	88	98	104	112
14,000	1,400	79	92	104	110	120
16,000	1,600	86	98	110	118	128
18,000	1 800	92	104	114	124	134
20 000	2 000	96	108	120	128	140
25,000	2,500	104	118	128	140	150
30,000	3,000	110	124	136	148	162
35,000	3.500	120	132	146	158	172
40 000	4 000	124	139	154	168	180
45,000	4,500	128	144	159	174	187
50,000	5,000	134	148	164	180	194
60,000	6 000	144	162	178	194	208
70 000	7,000	150	172	190	206	222
80 000	8,000	160	181	198	218	234
90,000	9 000	168	190	210	228	245
100,000	10,000	174	198	220	238	256

	Data on Which Table is Based				
Efficiency	68	68	68	65	63
CO₂	9	9.5	10	10.5	11
Stack Temp.	450	488	525	562	600

AVERAGE FRICTION LOSS THROUGH BOILERS (VARIES ACCORDING TO CONSTRUCTION)

Rating	100	150	200	250	300
In. Water	0.1 to 0.3	0.2 to 0.6	0.3 to 0.9	0.5 to 1.4	0.7 to 1.9

For furnace draft: Allow 0.15 for forced draft. For natural draft 0.35 in. or higher should be used, depending upon rate of combustion and fuel used.

II. HEIGHT OF STACK IN FEET

For Sea Level and 60° Outside Temperature and 0.1 Inch Friction Loss Per 100 Ft.

Total Draft Req'd, Ins., For Furnace, Boiler and Breeching	% of Boiler Rating				
	100	150	200	250	300
.3	56	...	...	...	...
.4	74	69	..	...	...
.5	93	86	81	...	...
.6	111	103	97	..	...
.7	130	120	113	108	...
.8	148	138	129	123	...
.9	...	155	145	139	132
1.0	...	172	161	154	147
1.1	...	190	177	170	162
1.2	...	...	194	185	176
1.3	...	...	209	200	191
1 4	...	...	226	216	206
1 5	...	...	..	231	221
1 6	...	...	...	...	236
1 8	...	...		..	265
Assumed Flue Gas Temp.	500	550	600	650	700

AVERAGE CONDITIONS FOR FORCED-DRAFT STOKERS (Sea Level)

% Rating	100	150	200	250	300
Draft, Furnace........	.15	.15	15	.15	.15
Friction Loss (Boiler)..	.18	.4	.65	.9	1.20
" " (Breeching)	.10	10	.10	.10	.10
Total Draft Req'd.....	.43	.65	.90	1.15	1.45
Height of Stack (Ft.)..	80	112	145	178	220

Correction for Altitude

Height Above Sea Level (Ft)	Ratio Increase in Diameter	Ratio Increase in Height
0	1 000	1.000
1,000	1.015	1 046
2,000	1 030	1 097
4,000	1 063	1.205
6,000	1 096	1 321
8 000	1 130	1 456
10,000	1.165	1.612

For breeching friction loss: Allow .05 in. for each right angle bend and 0.1 in. per 100 ft. of length. Cross sectional area of horizontal breechings should be 20% larger than that of stack, to allow for increased friction in a horizontal over a vertical column, as well as dust accumulations at the bottom.

With return tubular boilers it is common practice to provide 20% more stack area than the aggregate tube area, which is satisfactory for ratings up to 150%. The height has ranged from 25 ft. on smaller boilers, say 30 in. in diameter by 8 ft. long, to 60 ft. on boilers 72 in. in diameter by 18 ft. long. These heights provide draft sufficient for operating boilers at about rating when burning coarse bituminous coal, but are inadequate for high ratings and for burning fine coal. While overratings are difficult to obtain, on account of frictional loss in the fire-tubes, 200% is sometimes sought, and fuel-bed resistance may require higher chimneys than standard, and use can therefore be made of Tables I. and II. With stacks placed on top of boilers, 8 to 12 ft. should be added when height from the grate is considered.

Osborn Monnett made the following recommendations to the Smoke Prevention Association: Stacks should be so located as to give the most favorable run of breeching possible. Steel stacks should be lined for a height equal to 10 times their diameter. For water-tube boilers the free area of the stack at the smallest point should be not less than one-fifth the area of the total connected grate surfaces, where the stack is less than 150 ft. high. Where the stack is over 150 ft. high, the area should be not less than one-sixth the total grate surface. For horizontal return-tubular boilers the stacks should have an area in free opening at the smallest point 25% in excess of the combined area of the tubes served.

When small sizes of anthracite are to be burned, the stack height for natural draft becomes prohibitive, and mechanical draft must be utilized. To burn 25 lb. of pea coal per sq. ft. per hr. requires a 175 ft. stack To burn the same quantity of No. 3 buckwheat requires a 385 ft stack.

The table below, compiled by *J C Lathrop*, gives the principal data covering a number of **chimney installations.** No. 11 will serve 64 B.HP. per sq. ft. of chimney when the 12 boilers are installed. On the other hand, No. 16 has only 16 B.HP. per sq. ft The chimneys for the oil-burning plants have a high boiler capacity per sq. ft. of area, and their height need only be sufficient to carry the gases above the surrounding buildings.

SIZES AND CAPACITIES OF LARGE CHIMNEYS IN VARIOUS SECTIONS OF THE UNITED STATES

No.	Location	No. of Boilers Served by Stack and HP.	Type of Stoker Installed	Inside Diam , Ft and In	Inside Area, Sq Ft	Height Above Grates, Ft	HP Kent Formula	B HP. Con- nected	B.HP. per Sq Ft. of Chim- ney
1	New York	24-650	Taylor	21 0	345	250	17,600	15 600	45
2	Baltimore .. .	12 1000	Taylor	20-2	320	250	16.200	12,000	38
3	Akron, O.	16-600	Taylor	16 0	200	275	10,600	9,600	48
4	Boston	8-600	Taylor	13-0	132	210	6,000	4 800	36
5	Milwaukee . .	2-765	Taylor	8-0	50	125	1,710	1,530	31
6	Indianapolis ..	20-520	Roney	18-0	254	300	14,100	10 400	41
7	Georgetown . .	6-600	Roney	11-0	95	225	4,450	3,600	38
8	Utah	6-600	Roney	11-6	104	220	4,820	3,600	35
9	Meriden, Conn	4-625	Roney	9-0	64	150	2,420	2,500	39
10	Chicago	8-1220	Chain grate	19 0	284	250	14,400	9 760	36
11	Venice, Ill....	12-600	Chain grate	12-0	113	200	5 050	7,200	64*
12	Chicago	10-580	Chain grate	17-0	227	250	11,500	5,800	26
13	Perth Amboy .	8 600	Chain grate	14-0	154	180	6,550	4 800	31
14	Louisville, Ky.	8-507	Chain grate	13 0	132	255	6,660	4,050	31
15	Savannah, Ga..	4-700	Chain grate	10-0	78	230	3,660	2 800	36
16	Alton, Ill......	4-440	Chain grate	12-0	113	150	4 350	1 760	16†
17	Waterloo, Ia...	5-300	Chain grate	7-0	38.5	135	1,350	1 500	39†
18	Lexington, Ky.	8-500	Murphy	12-0	113	210	5,150	4,000	35
19	Gadsden, Ala..	6-600	Murphy	13-0	132	225	6,250	3,600	27
20	Fruitvale, Cal .	12-645	Oil burner	14-6	165	125	... .	7,740	47
21	Jacksonville .	12-520	Oil burner	12-0	113	180	....	6,220	53
22	N. Shore Cal.	3-265	Oil burner	5-0	19.5	70	.....	795	40

* Six boilers in place.   † Induced draft provided.
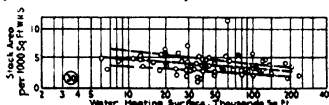
STACK AREAS IN MODERN PLANTS.—*Power*

The above chart, by *John G. Fairchild,* gives the ratio of stack area to heating surface in a number of modern plants, the dotted lines representing the mean and values 25% above and below the mean.

MECHANICAL DRAFT

Induced Draft.—Fans used for removing the gases from the furnace handle a product at high temperature, frequently heavily dust laden, occasioning excessive maintenance cost The volume is much greater than would be handled by a forced draft fan, and it might seem that the forced draft apparatus could be used to advantage in all cases However, it is important in most cases that a draft suction be maintained in the boiler setting, and this may necessitate an induced draft fan This insures against leakage of gases into the boiler room The steam consumption of an induced draft fan will be approximately 2 to 4% of the steam generated. If it creates too great a suction, it will cause inleakage of air through the setting and breeching, and increase the heat loss in the stack gases. Induced draft fans make it possible to draw off even the relatively-cool air from economizers or air heaters, which would otherwise require excessive stack height.

Forced Draft.—In the ordinary land installation the air under pressure is supplied to the ash pit, the plenum system (whole boiler room under pressure) being used only on shipboard The ash-pit must be tight and the air introduced in such manner as to give an even pressure distribution over the grate, in order that the fire may burn evenly. The power consumption of a forced draft fan should be less than that of an induced draft fan, because of the lower temperature, and hence smaller volume, of the cold air as compared with the chimney gases The actual steam consumption of forced draft fans varies from 2% of the total steam generated to much higher figures, due to the use of small, inefficient fans or small, cramped ducts It is desirable that the stack be capable of maintaining a suction throughout all parts of the boiler setting If such suction is not maintained, trouble will result with the brick work, as high temperature gases will tend to pass out through the cracks and pores in the setting, overheating it, whereas with draft suction cold air from the outside percolates in through the brick work, and reduces its temperature This suction is also necessary to secure the inflow of the proper amount of secondary air. It should not be less than about 0 03 in over the fire at all times. The action of the forced draft should cease at the surface of the fire, leaving to the induced draft from stack or fans the removal of the gases.

With a combination of forced and induced draft fans, it should be possible to balance the drafts so that a suction of 0 05 to 0.10 in. of water is constantly maintained immediately above the fire, as under such conditions no gases will leak out and a minimum will leak in.

D. S. Jacobus states that large furnaces, with boilers set 10 to 14 ft. high, as for stoker firing, are subject to brick-work trouble unless sufficient draft is provided. If a forced draft stoker is operated with too high air pressure, the gases tend to leach out through the setting, and an induced draft fan should then be provided if the stack capacity is limited. A suction of at least 1/20 in., and preferably 1/10 in., should be present in all parts of the setting, at all rates of combustion.
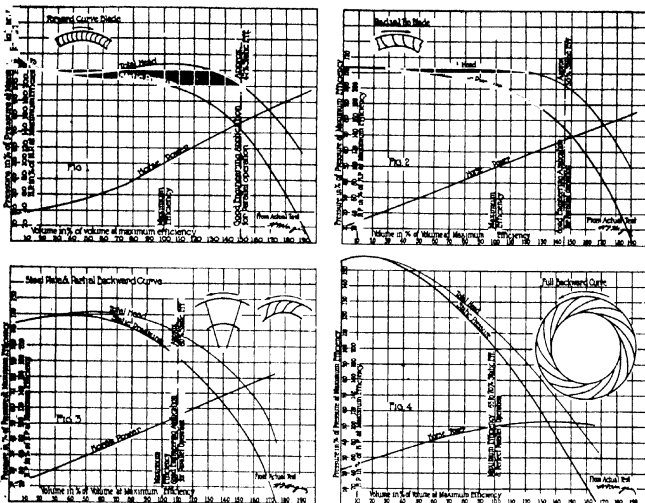
TYPICAL PERFORMANCE OF CENTRIFUGAL FANS

H. F. Hagen gives the accompanying four charts showing character-istics at constant speeds of various centrifugal fans classified with respect to the direction of the blade at the periphery. With the forward-curved blade the rotational component of the air velocity leaving the wheel is actually higher than the rotational speed of the wheel itself, giving a characteristic curve such that the delivery head tends to rise with increas-ing volume. The total head and HP. curves rise, the static pressure curve is flat or rises slightly, and maximum efficiency is where the static pressure just begins to fall. In the radial-tip fan, a multiblade fan with each blade tangent at the periphery to a radius of the wheel, the tendency is to maintain the pressure constant, and such a fan should give a total head curve practically flat to the point of extreme velocities, the static pressure steadily dropping but only very slightly. The partial-backward-curve fans have practically the same characteristics as the old-fashioned steel-plate or few-bladed paddle wheels, the pressure curve tending to fall continuously with increased volume, except possibly at very low volumes, while the maximum efficiency occurs where the curve is decidedly drooping. In the full-backward-curve fan the blade curvature is carried back to a much greater degree, and the pressure curve slopes more than with any of the other types, while the HP. curve, instead of being straight, rises to a maximum and then falls away. This self-limiting power characteristic

protects the motor from overloading, and is not found in the partial-backward-curve fan.

Both the forward-curved and the radial-tip are too low in efficiency and speed for forced-draft work, they have no reserve pressure, a reduction in volume being unaccompanied by an increase in pressure, and neither is adapted for operation in parallel, that is, with more than one fan discharging into a common duct. Even a slight change in speed produces a change in pressure, and with a flat characteristic a small difference in pressure is sufficient to cause a wide variation in volume before equilibrium is again established, so that the fans divide the load erratically. Fans with the steel-plate paddle-wheel characteristics are suitable for stokers, operate fairly successfully in parallel, and have "pressure reserve," but are too low in speed for modern drives. The partial-backward fan is practicable, having a reasonably high speed, yet the efficiency is not so high as that of the full-backward type and the HP. curve is straight, not self-limiting. The advantage of the self-limiting curve as developed by the full-backward-curved blade is that the maximum HP. can be made to coincide very closely with the peak of the efficiency curve, which is favorable to motor efficiency and power factor, and the driving motor cannot be overloaded. The efficiency of the full-backward-curved fan is inherently high, as a large part of the energy is already static pressure when the air leaves the impeller, and only a relatively small conversion of velocity into static pressure is required in the housing. The steep pressure curve indicates reserve pressure. If the fuel settles or clinkers start to form in the fuel bed, the volume of air passing through it decreases, and the fan, without change of speed, supplies an immediate increase in pressure, opening up the fuel bed and averting drop in boiler pressure.

Hagen suggests that when an induced-draft fan is used, it should be selected to operate efficiently at the normal load of the plant, but with ample leeway in motor capacity and speed to take care of 100% excess air for the maximum conditions, and that induced draft should not be used alone except for those stokers, such as some chain grates, which have a small draft loss through the grates and fuel bed. When both forced and induced draft are used, the induced draft should be called upon only to overcome the resistance to the flow of gases through the boiler and economizer and the necessary flues, and further to furnish a slight draft in the fire box. These resistances being substantially constant, the fan characteristic is not so important, and the paddle-wheel fan is suitable, as it accumulates little deposit in its large passages, and the speed is low enough not to produce vibration due to unbalancing from what does collect. Multi-bladed fans are used if direct connection to driving motor is demanded. With high boiler ratings, velocities and draft losses, temperatures of $600°$ or $700°$ F. at the fan, and pressures as high as 6 in. (equivalent in speed required to over 12 in. with cold air), one is often compelled from considerations of strength to select the fan which will give the highest pressure for the lowest tip speed—the forward-curved fan. The hot gases at the induced-draft fan usually have a volume twice as great as the air at the forced-draft fan, requiring twice the HP. to deliver them against the same pressure, so that the forced-draft fan should do all the work possible, a "balanced draft" condition being maintained in the furnace as nearly as practicable.

DRAFT REQUIREMENT WHEN HAND FIRING BITUMINOUS COAL
Buffalo Forge Co.

Excess Air %	% CO₂ From Flue Gas Analysis	Excess Oxygen O_2 %	Heat Carried Away in Chimney Gases %	Stack Loss Plus 10% Radiation Loss %	Efficiency of Boiler %	Lb. Air per Lb. Combustible Burned	Lb. Gases per Lb. Combustible	Lb. Combustible Burned per Boiler HP.	Lb. Air per Hr. per Boiler HP.	Lb. Gas per Hr. per Boiler HP.	Cu. Ft. Air per Min. per Boiler HP. 70° F.	Cu. Ft. Gases per Min. per Boiler HP., 300° F.	Do., 550° F.
0	18.2	0	10 2	20.2	79 8	12.0	13.0	2.74	32.9	35.6	7.32	10.89	14.47
20	15.1	3.6	12.1	22.1	77.9	14.4	15.4	2 81	40.5	43 4	9.01	13.35	17.74
30	13.9	5.0	13.0	23.0	77.0	15.6	16.6	2.84	44.3	47.2	9.85	14.58	19.37
40	12.9	6.1	14.0	24 0	76 0	16.8	17.8	2 88	48.4	51.3	10.77	15.88	21.10
50	12.0	7.1	14.9	24.9	75.1	18.0	19.0	2.91	52.5	55 4	11.68	17.18	22.83
60	11.2	8.0	15.8	25.8	74 2	19.2	20.2	2.94	56.5	59.4	12.57	18.45	24.52
70	10.6	8.8	16.8	26.8	73.2	20.4	21.4	2.98	60.8	63 8	13.52	19.87	26.38
80	10.0	9.5	17.7	27 7	72.3	21.6	22.6	3.02	65.3	68.3	14.53	21.28	28.28
90	9.5	10.1	18.7	28.7	71 3	22.8	23.8	3.07	70.0	73.1	15.57	22.80	30.30
100	9.0	10.6	19.6	29.6	70 4	24.0	25.0	3.12	75.0	78.1	16.68	24.39	32.40
125	7.9	11 8	21.8	31.8	68.2	27.0	28.0	3.22	87.0	90.2	19.35	28.24	37.52
150	7.1	12.7	24.2	34.2	65.8	30.0	31.0	3.32	99.6	102.9	22.16	32.27	42.88
200	5.9	14.1	29.0	39.0	61.0	36.0	37.0	3.61	130.0	133.6	28.92	42.02	55.85
250	5.1	15.1	33.5	43.5	56.5	42.0	43.0	3.84	161.0	164.8	35.81	51.94	69.02
300	4.4	15.8	38.4	48 4	51 6	48.0	49.0	4.28	205.0	209.3	45.60	66.06	87.78

Selection of Fans.—The *Buffalo Forge Co.* states that it is customary practice in selecting apparatus for mechanical draft to allow for 100% excess air for hand-fired boilers, say a total of 16.7 cu. ft. air per min. at 70° F. per boiler HP. for a forced draft fan, or 32.4 cu. ft. flue gases per min. at 550° F. per boiler HP. for an induced draft fan. For stoker-fired boilers, roughly 50% excess air can be allowed, corresponding to 11.70 cu. ft. at 70° F., or 22.8 cu. ft. at 550° F., per min. per boiler HP. More exact determination of quantity of gases can be made by the methods of pages 210 and 594, or the tables above and on p. 232.

EFFECT OF ALTITUDE ON AIR DENSITY
Buffalo Forge Co.

Altitudes in ft., densities compared with standard air at 0 alt., 29.92 in. bar.

Alt.	Den.	Bar	Alt.	Den	Bar	Alt	Den	Bar.	Alt	Den.	Bar.
0	1.00	29.92	1500	.944	28.26	3000	.891	26.68	6000	.795	23.79
100	.966	29.81	1600	.941	28.15	3200	.885	26.48	6200	.789	23.61
200	.992	29.70	1700	.937	28.04	3400	.878	26 28	6400	.784	23.43
300	.989	29.58	1800	.933	27 93	3600	.872	26.08	6600	.778	23.26
400	.985	29.47	1900	.930	27.83	3800	.865	25.88	6800	.772	23.08
500	.981	29.36	2000	926	27 72	4000	.858	25.68	7000	.766	22.90
600	.977	29 25	2100	.923	27 62	4200	.852	25.49	7200	.760	22.73
700	.974	29.14	2200	.919	27.51	4400	.846	25.30	7400	.754	22.56
800	.970	29.02	2300	.916	27.41	4600	.839	25.10	7600	.748	22.38
900	.966	28.91	2400	.912	27.30	4800	.833	24 91	7800	.743	22.21
1000	.962	28.80	2500	.909	27.20	5000	.826	24.72	8000	.737	22.04
1100	.959	28.69	2600	.905	27.09	5200	.820	24 53	8200	.731	21.87
1200	.955	28.58	2700	.902	26.99	5400	.814	24.35	8400	.726	21.70
1300	.952	28.47	2800	.898	26.89	5600	.808	24.16	8600	.720	21.54
1400	.948	28 36	2900	.895	26.78	5800	.802	23.98	8800	.714	21.37

EFFECT OF TEMPERATURE ON AIR DENSITY
Temperatures in ° F., densities compared with standard air at 70° F.

°	Den.	°	Den	°	Den	°	Den	°	Den.
—10	1.178	60	1.019	100	.946	200	.803	400	.616
—5	1.165	62	1.015	105	.938	210	.791	425	.599
0	1.152	64	1.011	110	.930	220	.779	450	.582
5	1.140	66	1.008	115	.922	230	.768	475	.567
10	1.128	68	1.004	120	.914	240	.757	500	.552
15	1.116	70	1.000	125	.906	250	.747	525	.538
20	1.104	72	.996	130	.898	260	.736	550	.525
25	1.093	74	.992	135	.891	270	.726	575	.512
30	1.082	76	.989	140	.883	280	.716	600	.500
35	1.071	78	.985	145	.876	290	.707	625	.488
40	1.060	80	.982	150	.869	300	.697	650	.477
42	1.056	82	.978	155	.862	310	.688	675	.467
44	1.052	84	.974	160	.855	320	.680	700	.457
46	1.047	86	.971	165	.848	330	.671	725	.447
48	1.043	88	.967	170	.841	340	.662	750	.438
50	1.039	90	.964	175	.835	350	.654	775	.429
52	1.035	92	.960	180	.828	360	.646	800	.421
54	1.031	94	.957	185	.822	370	.638	825	.412
56	1.027	96	.953	190	815	380	.631	850	.404
58	1.023	98	.950	195	.809	390	.624	875	.397

Dry air at 70° F. and 29.921 in. weighs .07495 lb per cu. ft.

Saturated mixture of air and water vapor at 70° F. and 29.921 in. weighs .07425 lb. per cu. ft.

DRAFT REQUIREMENTS OF UNDERFEED STOKERS
Westinghouse Elec. and Mfg. Co.

COMBUSTION RATE, LB. COAL PER SQ FT. PER HR.

	BTU per Lb. Coal as Fired											
	9000	9500	10000	10500	11000	11500	12000	12500	13000	13500	14000	14500
Min. ...	23	23	23	22	22	22	22	22	22	22	21	21
Max., cont. .	68	68	68	67	67	67	67	66	66	65	65	64
Max., peak load .	115	114	113	111	110	108	105	102	100	97	93	90

AIR VOLUMES REQUIRED PER LB. COAL AS FIRED

In Cu. Ft. at 70° F., 29.92 In. Bar ; to Convert to 100° F , Multiply by 1 058

	BTU per Lb Coal as Fired											
*	9000	9500	10000	10500	11000	11500	12000	12500	13000	13500	14000	14500
20	208	215	219	223	227	231	236	241	245	250	255	260
25	203	208	213	216	221	225	230	234	238	243	248	253
30	198	202	207	210	215	219	224	228	232	236	241	246
35	193	197	201	205	209	214	218	222	226	230	235	240
40	188	192	197	200	205	209	213	217	221	226	230	235
45	185	189	193	197	201	205	209	213	218	221	226	230
50	182	186	190	194	198	202	206	210	214	218	222	227
60	180	185	188	192	196	200	204	208	212	216	220	225
90	180	185	188	192	196	200	204	208	212	216	220	225

STATIC PRESSURE IN WIND BOX, IN IN WATER

20	.95	1.00	1.05	1.10	1.15	1.20	1 25	1.30	1.35	1.40	1.45	1.50
25	1.25	1.30	1.40	1.45	1 50	1.55	1.60	1.70	1.75	1.80	1.85	1.90
30	1.53	1.61	1.69	1.77	1.85	1.93	2.01	2.09	2.17	2.25	2.32	2.40
35	1.85	1.94	2.03	2.12	2.21	2.30	2.39	2.48	2.57	2 66	2.75	2.84
40	2.15	2.26	2.36	2 47	2.57	2.68	2.78	2.89	2.99	3.10	3.20	3.31
45	2.45	2.57	2.69	2.81	2.93	3.05	3.17	3.29	3 41	3.53	3.65	3.77
50	2.75	2.88	3.01	3.14	3.27	3.40	3.53	3.66	3.79	3.92	4.06	4.19
55	2.90	3.06	3.21	3.37	3.52	3.68	3.84	4.00	4.15	4.31	4.46	4.65
60	3.38	3.54	3.70	3 86	4.02	4.18	4.34	4.50	4.66	4.82	4.98	5.14
65	3.68	3.85	4.03	4.20	4.38	4.55	4.73	4.90	5.08	5 25	5.43	5.60
70	4.00	4.19	4.38	4.57	4.76	4.95	5.14	5.33	5.52	5.71	5.90	6.09
75	4.30	4.50	4.70	4.90	5.10	5.30	5.50	5.70	5.90	6.10	6.30	6.50
80	4.60	4.82	5.04	5.26	5.48	5.70	5.92	6.14	6.36	6.58	6.80	7.02
85	4.90	5.13	5.36	5.59	5.82	6.05	6.28	6.51	6.74	6.97	7.20	7.43
90	5.15	5.40	5.65	5.90	6.15	6.40	6.65	6.90	7.15	7.40	7.65	7.90

*Combustion rate, lb. coal per sq. ft. projected grate area per hr.

"Air volumes" in the above table include 35% for leakage between fan outlet and fuel bed. Pressures required for coals under 12000 *BTU* may vary somewhat from the figures given.

The static pressure to be imparted to these gases is the sum of the various resistances passed in series, distributed among forced and induced draft as desired. The curve on page 201 gives some of the commonly accepted values for draft required to overcome the resistance of the fuel-bed and grates.

For an induced draft fan, a boiler operating at 1600 HP. will require $1600 \times 17 = 27,200$ A P.M. (cu ft air per mln) at 70° F. If the altitude is 5200 ft. and the flue temperature 550° F, the product of the two correction factors (p. 232), is $0.82 \times 0.525 = 0.431$, hence the fan must remove $27,200/0.431 = 63,200$ A.P.M. at 550° F. If the air is to be moved against 2 in. static pressure, this corresponds to $2/0.431 = 4.65$ in. for standard conditions, and a fan is selected for 63,200 A.P.M. at 4.65 in. static pressure, requiring 79.4 HP., or $79.4 \times 0.431 = 34.2$ HP. under actual operating conditions.

If a forced draft fan is required for a 1500 HP boiler operated at 300% rating, 74% efficiency, over an underfeed stoker with 268 sq. ft. projected area, using coal of 13,245 BTU per lb as fired, the coal fed is

$$\frac{1500 \times 3.00 \times 33,479 \ BTU \text{ per boiler HP.-hr.}}{13,245 \times 0.74} = 15,370 \text{ lb. per hr., or}$$

$15,370/268 = 57.5$ lb. per sq. ft. projected grate area per hr. Interpolation in the upper table on page 232 gives 214 cu. ft air per lb. coal, or $214 \times 15,370/60 = 54,700$ cu. ft. air per min Interpolating in the lower table on page 232, it will require a pressure of 4.48 in under the grates for the same coal, or allowing 1 in. for duct and damper loss leading to the wind box, there must be a static pressure of 5.48 in. at the fan outlet, for 54,700 cu. ft. of air per min.

Turbines are used for driving fans mainly in large stations where the exhaust is utilized for heating feed water, and should be run at least 1500 rpm., using a reduction gear if necessary. Electric motors for driving fans should preferably be of the variable-speed type, d.c. or a.c., as constant-speed motors require regulating dampers and are wasteful of power. In large plants, a.c. motors of two different speeds can be used on the same fan. For boilers over 600 HP., each stoker should preferably have its own forced draft fan, although the ducts can be interconnected for emergency use.

John L. Alden gives the following formula for HP. input to fans:

$I = .000158 \ Qp/e,$ where

$I =$ input power supplied by motor

$Q =$ volume of air in cu. ft. per min.

$p =$ total head produced by fan, in in. of water

$e =$ efficiency of fan, expressed as a fraction.

The table below gives the range of fan efficiencies for types ordinarily encountered, from test figures. The second column shows why the extension of a duct system beyond the normal capacity of a fan results in a great increase in power consumption.

Type of Fan	Efficiency %	
	Rated Capacity	Maximum Capacity
Paddle wheel, 6-8 blades.....	40-45	20-27
Paddle wheel, 12-16 blades...	43-52	20-32
Multiblade, 30-64 blades	48-60	22-41
Pressure blowers	55-70	25-40
Turbo-compressors	65-80	29-55

The pressure to be developed by the fan is the sum of velocity pressure, entry loss, pipe friction loss and back pressure loss. The velocity pressure, in in. of water, equals $.000000063 \, v^2$, where v is the velocity in ft. per min. The entry loss at the opening of a straight suction pipe is 25% of the velocity pressure, and the corresponding loss through the open inlet of an ordinary fan is about 35% of the pressure due to the velocity through the inlet. The friction loss through pipe lines can be taken from Fig. C on p. 236, constructed from test figures on smooth metal pipes; 50% should be added to allow for ordinary roughness, rivet heads, solder, laps and dents. The chart is entered from below; the intersection of the vertical volume line with the velocity line gives the diameter, or vice-versa; and the horizontal line through the point of intersection gives the friction loss. The loss through 90° elbows is approximately as in the table below, the first line giving the throat radius in terms of pipe diameter, and the second the equivalent length of straight pipe, also in pipe diameters, to be converted to feet and added to the pipe length before determining friction loss.

AIR FRICTION IN 90° ELBOWS

Throat radius, diameters..	¼	½	¾	1	1½	2	3	4
Equiv. length straight pipe, diams.	67	30	16	10	6	4.3	4.8	5.8
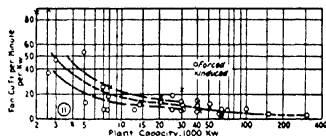
FAN CAPACITY IN MODERN PLANTS—*Power*

The above figure, by *John G. Fairchild,* gives the draft-fan capacity per Kw. in a number of modern plants, the dotted lines showing the mean and values 25% above and below the mean.
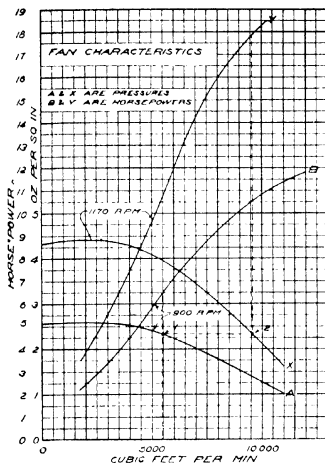
A. EFFECT OF SPEED ON FANS
—*Woodcraft.*
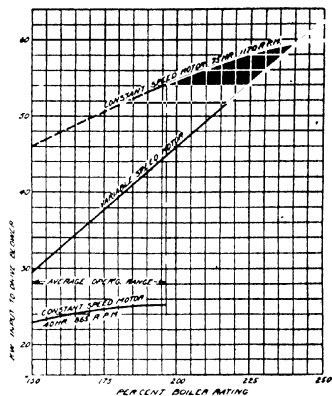
B. POWER CONSUMPTION OF MOTOR DRIVES FOR FORCED DRAFT BLOWER, 1500 HP, BOILER.
—*Power.*

Fan Power.—The *Bureau of Mines* warns that the attempt must not be made to put more air through existing boilers by overspeeding fans, since the power consumption will increase too rapidly. With a constant thickness of fuel bed, doubling the weight of air requires about $3\frac{1}{2}$ times the draft pressure difference, and trebling the weight of air about 6 times the draft pressure In the first case, the fan would require $6\frac{1}{2}$ times the weight of steam, and in the second case, 18 times the weight of steam. Therefore more efficient fans and more efficient engines must be obtained if grate surface and boiler are to be driven at very high ratings. Provided the boiler is such that the efficiency does not drop off too much when the capacity is increased, and the fuel is not easily carried from the fuel bed, an increase in rating is a sound step commercially. The steam from the fans can generally be used in a feed water heater.

The effect of running a fan under conditions different from those for which it is designed is shown by curves in Figure A. Fan manufacturers specify that a certain fan will deliver a certain number of cubic feet of air at a certain pressure when running at a certain speed. If, with the speed of the fan constant, the size of the opening be increased, more air will be delivered, but at a lower pressure.

At a speed of 900 rpm. the performance of a fan might be represented by the line A, while the horsepower taken by the fan would be represented by the line B. The first part of the pressure curve A is nearly horizontal, the point 1, where the line has taken a decided bend, is the delivery corresponding to what is usually termed the "blast area" of the fan, that is,
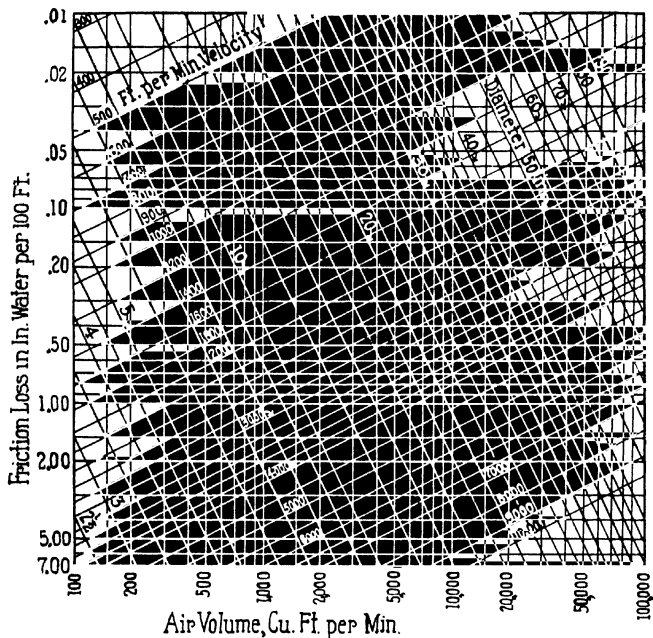
C. FRICTION IN AIR DUCTS (See page 234.)   —*Power.*

the largest orifice over which the fan will maintain approximately its maximum pressure. Fans are usually operated at some rate of delivery beyond point 1. If the speed of the fan be increased to 1170 rpm., the pressure at any given output will be increased, and the new characteristic curve will be X, while the power consumption curve will be Y. If the volume of air delivered be the same as for the lower speed, the fan is capable of maintaining a higher pressure, while if the pressure at which the air is required is the same as before, the fan is capable of delivering a much greater volume but in general with a still greater increase in power consumption. For instance, the power required when running at 900 rpm. for the delivery at point 1, is 6.4 HP. With the same pressure, the fan running at the higher speed of 1170 rpm. would give the increased volume shown at point 2, but would require the much increased power of 17.9 HP. Where the size of the openings and the length of the pipe remain constant, the volume of air handled by the fan increases almost directly as the speed, the pressure increases as the square of the speed, and the power consumed increases

as the cube of the speed. That is, by doubling the speed, twice the amount of air will be handled, at a pressure four times as great as before, and using eight times as much power for the fan. It is readily seen, therefore, that if more air is required, but not more pressure, it is generally poor policy to obtain increased volume of air by speeding up the fan. It would be better to install a larger fan or to add a second one.

In the 60,000 Kw. Government Nitrate Plant, each 1500 HP. boiler was equipped with an underfeed stoker and a radial flow fan, although a fan could be made to serve two boilers in case of emergency. Each fan had two motors, one at each end of the shaft, the 40 HP. fan being used up to 190% boiler rating, and the 75 HP. fan for occasional heavier demands. The air pressure at the stoker was controlled by a motor operated damper. The reason for this arrangement is apparent in Fig. B, p. 235, by *Edward R. Welles* and *W. A. Shoudy*, comparing the power consumption with that of a single variable-speed motor.

Mechanical draft is affected by the state of the atmosphere in the same way as is natural draft, but any deficiency can be supplied by increasing the speed of the fan

<div style="text-align:center">

FAN DATA ADOPTED MAY 31, 1923, BY THE
STOKER MANUFACTURERS' ASSOCIATION

</div>

DUCTS:

(a) *Velocities and Duct Proportions.* The area of the main air ducts shall be determined by using a velocity in the ducts based on a velocity pressure of from 5% to a maximum of 10% of the static pressure. The area of the branch air ducts leading to boilers should be such that the velocity will not be more than two-thirds of that in the main ducts. The following table shows the relation between velocities and static pressures on this basis:

Static Pressures	Ft per Min Velocity in Main Air Duct = 5% of Static Pressure	Ft per Min. Velocity in Main Air Duct = 10% of Static
2″	1300	1800
2½″	1400	2000
3″	1550	2200
3½″	1700	2400
4″	1800	2550
4½″	1900	2700
5″	2000	2850
5½″	2100	3000
6″	2200	3100
6½″	2300	3250
7″	2400	3350

The above table is based on a weight of air of 0.075 lb. per cu. ft., which corresponds to a temperature of 68° F., a barometric pressure 29.92 in. (sea level) and 50% relative humidity. (For higher elevations or temperatures, the above velocities may be increased 1% for each 500 ft. increase in elevation, and 1% for each 10° F. increase in temperature.) Any change in the direction of the air flow should be accomplished by means of bends having a radius of throat not less than one-half the diameter of a round duct or one-half the width of a rectangular duct.

With rectangular ducts, the ratio of one side to the other should prefer-
ably be not greater than two to one. For rectangular ducts having a ratio
of one side to the other greater than 2/1, lower velocities are recom-
mended, the reduction being 5% for a ratio of sides of 3/1; 10% for
ratio of sides of 4/1; 15% for ratio of sides 5/1; etc. Dampers in air
ducts should be located at points where the air velocity does not exceed
the velocities specified above.

(b) Construction: Air ducts shall be constructed so as to be smooth
and air tight. Where concrete or masonry ducts are used, the interior
surface shall be coated with cements, paints, or other materials that will
prevent air leakage. If the ducts are of metal construction, particular
attention shall be given to making the joints air tight. Where ducts are
located underground, sewer drainage shall be provided at the lowest
point, and manholes or doors provided for access to the ducts.

(c) Design of Fan Discharge Connections and Main Ducts: If the
fan outlet velocity exceeds the velocity in the main air duct, the connec-
tion between the fan discharge and the main air duct shall be straight
and of such length that the slope of any side relative to the axis of the
duct will not exceed one to eight. If the discharge connection expands on
one side only, the slope relative to the axis of the duct may be one to five.
Changes in section of the main air duct shall be made to conform with
the above recommendations. If the fan outlet velocity is not greater than
the velocity in the main duct, the fan may discharge directly into the duct,
unless the proportions of the fan outlet and duct are sufficiently different
to require a transformation piece, in which case the above recommenda-
tions shall apply.

(d) Branch Air Duct: Branch ducts shall not be taken from the
connection between the fan discharge and the main duct. Where the
direction of air flow in the main duct is constant, branch ducts shall be
taken off the main duct at an angle of 45°. Where the air flow in the
main duct may be in two directions, the branch ducts shall be taken off
at right angles to the main duct, with a radius of throat not less than
one-half the diameter of a round branch duct or one-half the width of a
rectangular branch duct.

(e) Parallel Operation of Fans: Only fans with rising pressure
characteristics shall be used for parallel operation. A fan is of rising
pressure characteristics type when the pressure curve rises continuously
from free delivery to no delivery condition. If two or more fans dis-
charge into the same duct, the connections from the fan discharge to the
duct shall be designed so that the frictional loss in each case between
the fan discharge and the duct will be equal. If two or more fans dis-
charge into the same duct with the same constant direction of air flow,
the connections from the fan discharges to the duct shall be designed so
that the air streams at the point where they merge will be flowing in a
parallel direction.

Guarantee: The guarantee of a fan duty should be understood to
cover the performance based on the capacity and pressure developed ¡ʌ
the fan discharge. If the conditions of the installation do not permit c
an accurate field test, a laboratory test shall be made on a fan of simila
type and proportions, but not of a larger size. The expense of tests t
demonstrate a guarantee shall be paid by the party requesting the te
unless the test demonstrates that the guarantee has not been met. Fa

tests and the determination of the results of tests shall be governed by, and be in accordance with, the code proposed by the joint committee of the American Society of Heating and Ventilating Engineers and the Association of Fan Manufacturers, or as later adopted by the American Society of Mechanical Engineers.

The Prat Induced Draft System in connection with Évasé (vase-shaped) or Venturi chimneys has been much used in Europe for the securing of draft with minimum expense for chimneys, and with small blowers handling only a fraction of the gases. In the outer-circuit type, shown in Fig. *A*, a jet of outside air is discharged through a nozzle at the base of a "diffuser," producing a partial vacuum which induces a flow of gas through the boiler passes and furnace. Similar results are secured from the inner-circuit system, Fig. *B*, where a portion of the flue gases is by-passed through the blower, and creates the draft for handling the main current. In this latter method, the fan is subjected to deterioration from the hot gases, but the reduction in draft due to the introduction of cold air into the chimney is avoided. With high furnace resistance, forced draft is desirable for continuous service, but the évasé system will compete

A. ÉVASÉ STACK, OUTER CIRCUIT.

—*Engg. Mag.*

B. ÉVASÉ STACK, INNER CIRCUIT
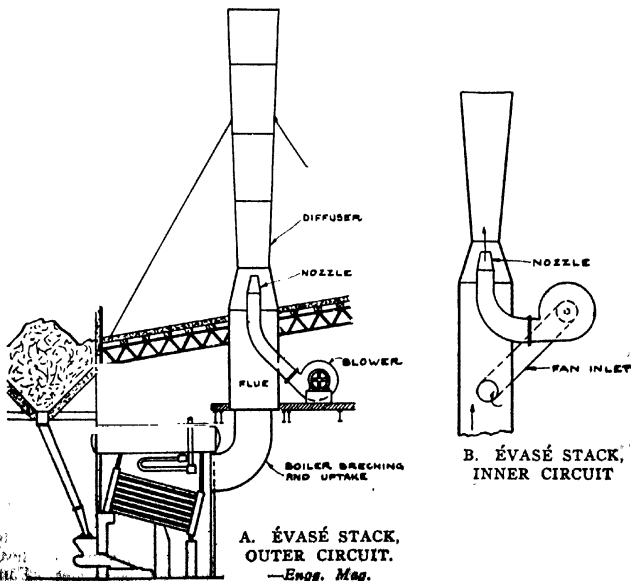
favorably for intermittent use. Under special conditions where the boilers are forced for short periods to three or four times their rated capacity, the évasé stack can be used in connection with either a chimney or a forced draft equipment. The small chimney required is built of sheet metal with increasing cross section, or the diffuser can be introduced into existing chimneys, as in Fig. C, thus increasing the available draft.
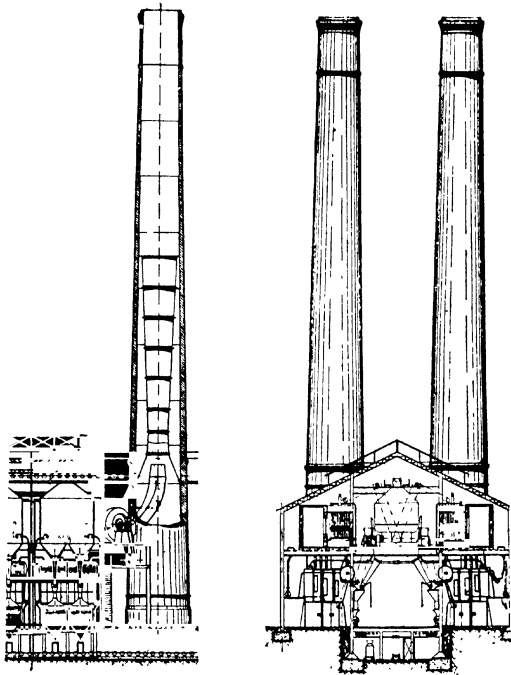
C. ÉVASÉ STACKS CONSTRUCTED IN EXISTING STACKS —*Combustion*

In the Paris power stations of Saint-Ouen and Issy-les-Molineaux, each battery of ten B&W boilers is served by a 208-ft. chimney, which under normal conditions furnishes the draft for burning 22,000 lb. of coal per hr., while with the inner-circuit system within the stack in operation, it is possible to increase this to 45,100 lb. of coal per hr. under the worst atmospheric conditions. There are two 80 HP. blowers, and the draft equipment consumes about 0.88% of the maximum steaming capacity of 308,000 lb. per hr.

Steam Jet Draft.—The jets may be placed either in the ash-pit or in the flue, producing forced or induced draft. The advantage of producing draft by a jet lies almost entirely in its cheapness of installation and low cost of repair. Its use is confined to small plants where the cost of a fan is not warranted, and to use in larger plants for carrying short peak loads. Its disadvantages are large steam consumption, limitation of draft produced, and noise

A. D. Pratt states that the maximum ash-pit blast that can be obtained from jets is approximately 1 in of water, while draft suction in the flue can be produced up to ¾ in above that which the stack alone would give. A ring of jets should be used in the stack to produce any appreciable results. The steam jets must be properly placed in the ash-pit in order to give an even distribution of draft pressure and thus produce an even fire. Steam consumption may run as high as 30% of the total steam generated, an ordinary figure being 5 to 10% Under test conditions, figures as low as 2½% have been obtained 4 to 6% will probably be good average practice.

D. Brownlie states that in 54 British hand-fired plants investigated, in which steam jets were used to create draft, the average steam consumption of the jets was 66% of the production, the individual figures ranging from 3.2 to 15.25%, while in 76 mechanically-fired plants the average was 6.7%, minimum 2.3%, maximum 13 8% He states, however, that a properly-designed and operated steam-jet apparatus uses only 1½ to 4% of the steam generated, while probably two-thirds of the jets are quite unsuitable for the conditions under which they are used and should be replaced by mechanical draft, taking about 2½% of the steam production.

DRAFT GAGES

The simple draft gage indicates the difference in pressure between the point to which it is connected and the atmosphere. A differential draft gage indicates the difference in pressure between two points in the gas passages.

Ordinary draft gages are modified forms of the U-tube. As the pressures are usually very small, water or oil is used as the liquid in the tube. Oil has greater uniformity of capillary attraction and minimum evaporation. Gages are calibrated for a given mineral oil, which is usually colored red, and the specific gravity of the proper oil must be known in making a replacement. For greater accuracy in reading the pressure, one leg of the tube is sometimes inclined.

Efficient combustion requires that a certain amount of air be provided for each pound of fuel burned When combustion is progressing properly the quantity of gases will be in direct proportion to the boiler load. The gases pass through the boiler, which has a constant resistance A differential draft gage indicating the pressure drop through the boiler will therefore act as a gas flow meter and show whether the proper quantity of air is being supplied for a given load.

A draft gage connected to show the pressure drop through the fuel bed, in connection with one showing the drop through the boiler, will indicate any change in the fuel conditions. A relative increase in the fuel bed drop will indicate that the bed is becoming thicker, or that it is becoming clogged with clinker, etc. Similarly, if the pressure drop becomes less, it indicates that there are holes in the fire, or that the fuel bed is too thin. The above principles are made use of in so-called combustion meters and efficiency indicators.
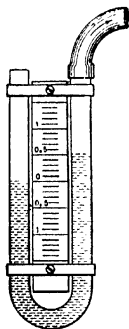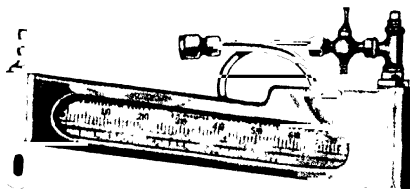
HAYS DIFFERENTIAL DRAFT GAGE

U-TUBE DRAFT
GAGE
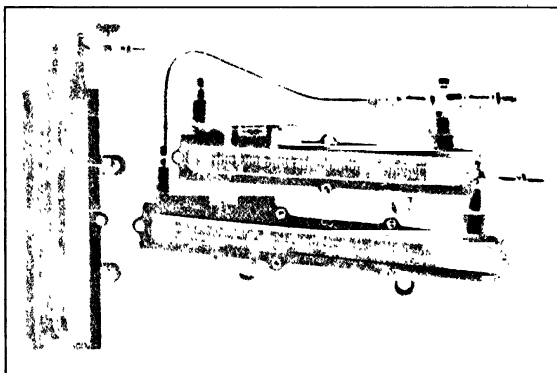
ELLISON U-MULTIPLE DIFFERENTIAL DRAFT GAGE

The Ellison Multiple Differential Draft Gage consists of multiple gages and a U-gage mounted on the same base, complete with connections and dust-proof vent caps. The U-gage indicates the blast, the upper inclined gage the furnace draft and the lower inclined gage the drop between the flue and furnace (boiler resistance). Each gage has movable pointers, the range of each scale being indicated. For balanced draft the furnace gage has a scale reading 0.05 in. to the left of zero for momentary pressures in the furnace above the atmosphere, and 0.45 in. to the right of

zero for the suction, the liquid movement being multiplied 15 times. On this gage the indicating tube lies near the upper edge of the scale, bending down at the chamber to prevent the liquid pulling through from a momentary excess furnace draft.

The Blonck Efficiency Meter consists of two differential draft gages, the one indicating the pressure drop through the boiler and the other the pressure drop through the fuel bed

The Bailey Boiler Meter combines a differential draft gage with a steam flow meter enclosed in the same case, both recording on one circular chart. The pressure drop in the boiler gas passages is an indication of the quantity of air passing through the boiler, and the pen recording this pressure is set to record just ahead of the steam flow pen. The instrument is so adjusted by means of CO_2 determinations that when the two lines practically coincide, the air is in the proper proportion for the load on the boiler. The steam record is made as a percentage of the rated capacity of the boiler.

The amount of air required to produce a given amount of heat is practically the same for all forms of fuel, from coal to natural gas. By comparison of the steam flow with the air flow, it is possible for the fireman to judge how perfect combustion is and to prevent undue losses in either excess air or unburned gases. *E. G. Bailey* states that such comparison soon shows the maximum economical capacity of an installation. If, for instance, the air supply is only sufficient for operation at 200% rating, any greater rate of forcing will produce very large amounts of unconsumed gases.

Figures on page 244 show the proper locations of draft connections, Where possible, the two connections for a differential gage should be placed on the same level, in order to eliminate errors in draft readings due to the difference in weight of the columns of gas in the pipe connections and in the furnace. For the boiler draft gage the connections can readily be put on one level. For the gage across the fuel bed, the two connections must necessarily be 18 or 20 in. apart vertically. However, this introduces but a slight error.

DAMPERS AND THEIR USE

According to *Osborn Monnett* dampers for horizontal return-tubular boilers should occupy the full width of the available opening and have a free area 25% in excess of the combined tube area. No type of damper plate that restricts the opening should be used.

For water tube boilers, a free opening of one quarter the grate surface should be provided and the dampers when wide open should hang in such a manner as not to obstruct the movement of the gases. He recommends that no damper be placed in the main breeching.

To calibrate the damper, connect a differential draft gage around the damper. Place the damper in the extreme closed position, open gradually and mark the position when the draft gage is first affected. Continue opening the damper until the gage registers no draft drop. Mark this position. Adjust the damper to work between these two positions.

Damper controls are preferably placed at the boiler front, where they can easily be reached and used by the firemen.

CONNECTION FOR
GAGE ON BOILER
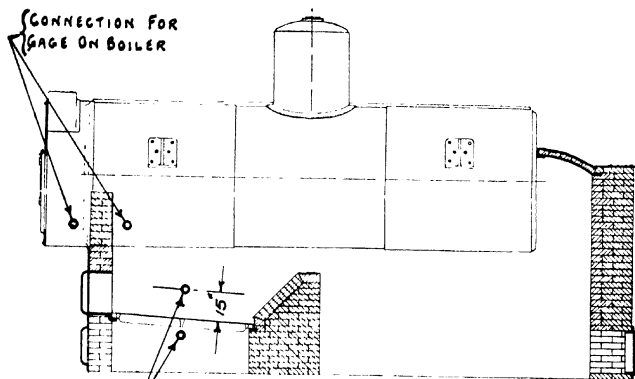
CONNECTION FOR GAGE ON FUEL BED
LOCATION OF DRAFT GAGES ON H. R T. SETTING

CONNECTIONS FOR GAGE ON BOILER
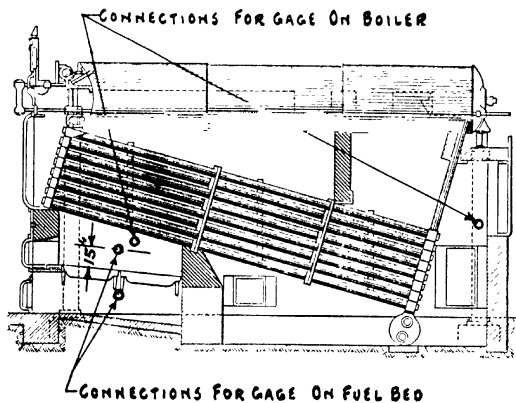
CONNECTIONS FOR GAGE ON FUEL BED
LOCATION OF DRAFT GAGES ON B & W. SETTING
—*Steam.*

There are two classes of automatic damper regulators; first, machines that move the damper for slight changes of steam pressure, the movement being more or less proportional to the change of pressure; and second, machines that swing the damper between extreme positions when the steam

pressure changes. *Hays* says that the first class is the better. The second does not meet the requirements of economical combustion. With the damper open, CO_2 percentage falls, due to air excess; with it closed, CO forms, due to lack of air. Machines of the first class may not make as perfect a steam pressure curve as the second, but will show better economy.

The *Bureau of Mines* says to use high draft with high rates of combustion, and low draft with low rates of combustion. It is impossible to get a high rate of combustion with a low draft, but very frequently high draft is used for low rates of combustion, using 30 to 40 lb. of air where 15 should be used. Regulate the draft by the damper. Arrange the latter so that the fireman can easily set it from the floor level.

Many serious cases of draft trouble could be cured by adjusting the boiler dampers to equalize the draft among the boilers. To equalize the draft among the boilers, get the fires all in standard condition, that is, the same thickness, free from air holes and clinkers. Adjust each boiler damper to the standard draft. Thereafter the main breeching damper alone should be used to regulate the draft to meet the load.

Change the position of the damper gradually. If the steam pressure is high, the damper should not be closed off entirely in order to let the pressure drop, then opened full to get the pressure up. This causes the draft and the air supply to vary excessively. Poorly adjusted automatic dampers cause similar variations.

Draft regulation by the ash-pit doors has very bad effects. It shuts off the air supply through the fuel bed; the ash on the grates and the grate bars become heated, and clinker and warped grates result. It is true that closing the ash-pit door cuts down the air supply, reducing the rate of combustion, but the draft in the setting is increased and more air is drawn into the furnace and all parts of the setting through the doors and cracks, entirely out of proportion to the coal burned. Air enters through the fuel bed, the furnace doors and cracks in the setting, and by closing the breeching damper all are reduced in proportion. By closing the ash-pit door, the supply through the fuel bed is reduced, but all the others are increased.

Automatic Combustion Control Systems are being introduced which take account of the boiler pressure, the flow of steam, the flow of air, the rate of feeding fuel, and the combustion chamber pressure in each furnace of a battery of boilers or of an entire boiler plant, and simultaneously make such adjustments of stokers or fuel feeders and of fans and dampers as are required to preserve constant steam pressure, to secure the desired division of load among the boilers, to insure the most favorable percentage of excess air or of CO_2, and to hold the most favorable furnace pressure. Increase of combustion rate starts the moment that increase in steam flow begins, and combustion is arrested promptly when steam demand decreases. Each fire receives only its allotted air supply, regardless of whether it is thick or thin, or whether one or several fires are fed from a common duct or from one fan, or whether draft is provided by one or more chimneys. The quantity of air supplied to burn each pound of fuel is definite.

In the *Gibson* system of metered combustion control, as supplied by the *Leeds & Northrup Co.*, the rate of flow of steam is measured by the pressure drop in the steam main, and the rate of flow of air or gases by the pressure drop or draft difference due to flow through a duct or a part of the boiler setting, while the speeds of stokers or fuel feeders are measured by centrifugal or electrical tachometers. The metered quantities are correlated through the medium of an electrical current, which can be subdivided

as desired among several furnaces or boilers. The current, about ⅓ ampere per boiler, acts in conjunction with the flow or speed metering devices to operate relays controlling electric motors, which perform the actual regulative operations. The regulative actions are progressive, continuing until the desired proportionality or balance between gas flows, fuel feeds, etc., is obtained. Control, is, therefore, unaffected by changes in resistance of gas passages, in thickness of fuel beds, in draft intensity produced by chimneys, etc., and metered quantities of fuel and air are fed to each boiler in an exact and predetermined ratio and in immediate response to station load demand.

The diagram on page 247 shows a typical hook-up for a **stoker fired plant.** The master controller is connected to the steam header at a point such that the drop in pressure below standard boiler pressure is indicative of total boiler load. The control system receives direct current at substantially constant voltage, and the master controller moves the rheostat arm in such a way that the current flow through the control system is proportional to the steam load, the remainder of the control circuit having a constant resistance. If desired, the control circuit can also be regulated by a master hand rheostat. From the master control board the current subdivides among the several active boilers of the station, the circuit of one being shown in the diagram.

The control current distributed to a given boiler passes first through the solenoids of the air-flow controller, the oil sealed bell of which responds to the drop in pressure due to the flow of gases through the last two passes of the boiler. When the balance is in equilibrium, the gas flow bears a fixed ratio to the control current, and, therefore, to the boiler load. As soon as a condition of unbalance occurs, contacts are closed which start the reversible motor of the drive unit which operates the uptake damper. When the damper approaches a wide open position, contacts are closed which cause the controller drive unit at the induced draft fan motor to move the controller up one notch. An interruptor circuit opens the fan control circuit for intervals sufficient to allow the fan to speed up. If the damper is still wide open when the circuit is again closed, the fan motor-controller is moved up another notch, and so on. The reverse action takes place when the damper closes beyond a predetermined point.

From the air-flow controller, the control current is led to the furnace pressure controller. The space under the bell of this controller is in communication with the over-fire chamber of the furnace, while the space above the bell is in free communication with atmosphere. The control current passing through the solenoids of the furnace-pressure controller is thus balanced against furnace vacuum. Unbalance of the furnace-pressure controller operates a drive unit connected to the damper in the forced draft duct. The value of the furnace vacuum maintained can be altered by means of a knob which varies the tension of a loading spring. The damper drive unit is provided with control contacts for the forced draft fan. These contacts notch up a controller to increase the fan motor speed when the damper approaches the wide open position and to reduce the fan motor speed when the damper closes too far. The control current next passes to the stoker controller, where it acts through solenoids opposing the suction generated by a small blower connected to the stoker drive and serving as a tachometer. Lack of balance causes a motor-drive unit to adjust a rheostat in the field of the stoker motor, as required to maintain fuel feed proportionate to air flow and to steam consumption.

The portion of the control current distributed to each boiler is deter-

FAN MOTOR
SPEED CONTROLLER

DC

DRIVE UNIT

FAN CONTROL
CONTACTS

DC

DRIVE UNIT

MASTER
CONTROLLER

D.C

STEAM
HEADER

STATION
LOAD
INDICATOR

BOILER LOAD
INDICATORS

BOILER
NO 1

BOILER
NO 2

BOILER
NO 3

AIR FLOW
CONTROLLER

STOKER
CONTROLLER

DC

STOKER MOTOR
SPEED CONTROLLER

DRIVE UNIT

FURNACE PRESSURE
CONTROLLER

STOKER
TACHOMETER

FAN CONTROL
CONTACTS

DRIVE UNIT

DC

DC

DRIVE UNIT

GIBSON COMBUSTION
CONTROL SYSTEM
FOR STOKER
FIRED BOILER

FAN MOTOR
SPEED
CONTROLLER

mined by the setting of an individual hand rheostat (not shown) in each boiler circuit. This rheostat also affords manual control of combustion rate at the corresponding boiler when operating on "individual" control. The total station load is indicated by an ammeter in the circuit of the master controller, while the loads borne by individual boilers are shown by separate boiler load indicators on the individual boiler boards. The motor-drive units of the several controls can, upon occasion, be operated by push-buttons from the individual boiler boards, or the drive units can be disengaged and the dampers and motor speed controllers operated directly by hand.

For a **powdered fuel plant** certain additional devices provide supplementary regulating effects desirable in the burning of powdered fuel. The secondary air shutters regulate the distribution of the secondary air to the furnace according to load and are operated by a motor drive unit in response to the control current. The speed of each fuel feeder is kept in a fixed ratio to the main control current by a voltage balance controller, which balances the aggregate voltage generated by the electric fuel feeder tachometers against the voltage drop due to the flow of control current through a resistance. The ratio between control current, and hence air flow, and the sum of the speeds of the several fuel feeders, may be modified by adjusting this resistance manually, or automatically by a fuel-air ratio controller responding to some condition of furnace operation, as, for example, the CO_2 content of the flue gases. In this way irregular feeding due to the non-uniform physical characteristics of powdered fuels, or varying heating values of different fuels, can be compensated for automatically.

Automatic combustion control gives three principal advantages, namely, **completely automatic and reliable operation**, with a minimum of supervision or manual intervention; **uniform steam pressure** in the delivery header, which implies steam generation in immediate and direct response to demand at all times; and **percentage of CO_2** in flue gases as high as is compatible with economical operation of the furnaces, when maintenance, combustible in ash, and combustible lost up the stack are all considered. The operator is left free to devote his thought and attention to building up those conditions most conducive to maximum efficiency, as by study of flue gas composition or other factors affecting efficiency, by refining adjustments, by attention to individual fires, stokers, or settings, and by comparing fuels. Once he settles upon certain ratios or constants, they are thereafter maintained for him automatically.

ANALYSIS OF GASES OF COMBUSTION

The flue gas analysis is the means for studying and obtaining the proper combustion conditions and for determining the amount and distribution of some of the heat losses in boiler operation. For most purposes it is necessary only to take the % CO_2. This should be taken very frequently (as often as once a minute) while the conditions are being changed.

The following are the things to be studied and adjusted:

1. The firing and handling of the fire.
    - (a) Selection of proper firing method for the coal in use (coking or spreading methods).
    - (b) The proper leveling of the fire to keep it free from air holes.
    - (c) The proper depth of fire.

2. The draft for the thickness of the fire and the load.
3. The setting, which should be free from cracks.
4. The secondary air supply, which must be provided to complete
    combustion.
5. The furnace construction.

The quantities usually determined in a flue gas analysis are the relative proportions by volume of CO_2, O_2 and CO. The free H_2 is sometimes determined where more accurate results are desired, but unless the CO is over 0.5%, determination of H_2 is useless. The analysis gives the % by volume. To obtain the % of the constituents by weight, multiply the % volume by either the density or the molecular weight, and divide each product by the sum of all the products. The even values of the molecular weights are: $H_2 = 2$, $CO_2 = 44$, $CO = 28$, $O_2 = 32$, $N_2 = 28$.

SAMPLING OF GASES OF COMBUSTION

In order for the gas analysis to have any value, the sample on which it is based must be as nearly an average as it is possible to obtain. There seems to be some diversity of opinion as to the best method of taking the sample. For sampling furnace gases the *Bureau of Mines* recommends a water-cooled tube or a quartz tube as preferable to a plain metal tube. An open-ended tube placed in the center of the stream of gases gives with water-tube boilers results within 0 5% of the average composition, if the setting is fairly tight. For more exact work the sampler tube may terminate at the middle of a 1-in. iron pipe reaching across the up-take or smoke box, closed at the ends and drilled on opposite sides with $\frac{1}{16}$-in. holes 6 in. apart. A "spider," by means of which a larger volume of gases is brought together at one point and the sample drawn therefrom, is shown in Fig. A.

A. SPIDER FOR
SAMPLING FLUE GAS

B AND C. FLUE GAS COLLECTORS
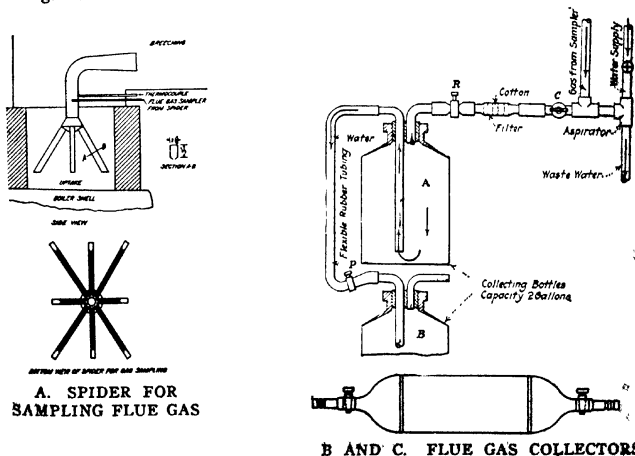
The proposed Test Code of the *American Society of Mechanical Engineers* states that the standard flue-gas sampler shall consist of an open-ended iron exploring tube, with the open end of the tube placed at the position in which the gas velocity attains the arithmetical mean of velocities across the section, as determined by preliminary exploration and judgment, avoiding pockets back of dampers and at bends. The thermometer bulb or hot junction or other device used for temperature measurement shall be placed as near the open end of the sampling tube as possible and in such a position that the stream flow impinges freely on it. The element must be protected from colder or hotter surfaces in the vicinity, by metal, asbestos or other shields so placed that no direct radiation can take place to or from the element. The gas sample shall be carried from the open-ended pipe in a single tube to the aspirator by a strong and continuous aspirating process. It is preferable to have the sample drawn directly into the Orsat apparatus, but where this is not feasible, the gas sample shall be collected at the aspirator in standard collecting bottles, Fig. B, or in tin tubes, Fig. C. The gas is drawn in by an aspirator if at a pressure below normal, but if it is at a pressure above normal it will readily displace the water in the container. The gas samples may be collected in quantities proportioned to the rate of burning fuel, or they may be collected in equal quantities at equal intervals of time. In the latter case the average analysis of the gases must be arrived at by weighting the separate determinations proportionally to the weights of fuel burned during the times of collecting the samples. Whenever possible the analysis shall be made immediately after collection of the sample.

Charles Gordon Thatcher gives in Fig. D curves of equal CO_2 readings, also of equal temperatures and gas velocities perpendicular to a horizontal plane in the last pass of a 10,000-sq.ft. horizontal water-tube boiler, stoker fired at 120% rating. The average CO_2, with the readings weighted according to flow, was 13.105%, while the simple average was 12.95% and the value at the center of the pass was 14.6%. The special sampler illustrated gave, in a single reading *at this load,* almost exactly the computed average CO_2. With another boiler the sampler indicated, at 100% rating, ½% more CO_2 than the calculated average, and at 275%, ½% less. The size of openings of such a device could be modified so as to give practically a true average at any given rating, but not for all ratings.
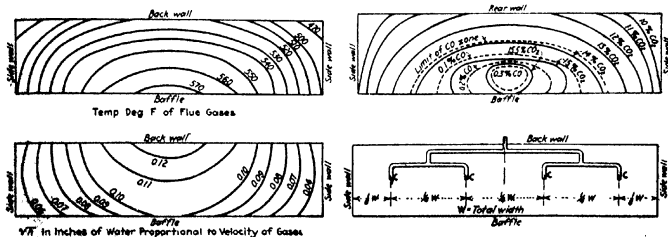
D. GAS READINGS IN LAST PASS, AND SPECIAL SAMPLER.—*Power.*

The *Bureau of Mines* states that it is advisable to connect the gas sampler to a water aspirator, so that a continuous stream of gases is maintained through the connection. A tee in the line on the upstream side of the aspirator permits a sample to be taken off by the collector or by the analyzing apparatus. Such an aspirator can be constructed of pipe fittings, or a simple aspirator can be purchased. An aspirator or ejector constructed from pipe fittings is illustrated. There should be no pockets in the gas line which would fill up from the condensed water vapor always contained in flue gases. Where a sample is to be taken immediately into the Orsat, an open-ended tube should be used. This should be as small as practicable, in order that the volume of air may be as small as possible, and quickly drawn out Ordinarily filling the burette two or three times suffices to remove

DETAILS OF ASPIRATOR AND CONNECTIONS

the air. If only CO_2 is to be determined, a $\frac{3}{16}$ or $\frac{1}{4}$ in. copper tube is a good sampler. A $\frac{1}{4}$-in. copper tube will hold approximately 1 cu. in. of gas for every 3 ft. of length. The capacity of a $\frac{1}{4}$-in. standard iron pipe is about 1 cu. in, for every 10 in. of length.

One gas sample per hour is very little better than no gas sample at all. It is not enough to indicate an average. The sample should be taken every 5 min., and a continuous sample would be better. Speed is absolutely essential in taking gas samples. Conditions may change from instant to instant. The conditions at the time of taking the sample should be recorded in order to be able to determine the meaning of the analysis.

The use to be made of gas analysis determines the location of the sampling tube. If the total heat losses are the desired data, the sample should include all the air leakage into the setting. If the information is to be used in controlling the fire, the gas samples should be taken at some point before they are diluted by leakage through the setting. The following figures from tests by the *Bureau of Mines* show that this leakage is considerable, even in a well-maintained setting:

	CO_2	O_2	CO	CH_4	Sum.
Rear of combustion chamber, average %	14.5	3.3	0	0	17.8
Base of stack, average %	10.7	8.1	0	0	18.8

An average of 32 tests showed that the weight of gases per lb. of fuel increased 22.4% between the end of the combustion chamber and the stack.

Hays recommends taking flue gas samples at the point where the gases leave the heating surfaces of the boiler, in order to catch all of the air leakage that is really affecting efficiency. Remember the boiler damper in placing the sampling tube, so that the tube is not placed in a gas pocket. Particular attention must be paid to preventing air leakage around the sampling pipe, which might give a false indication of the composition of
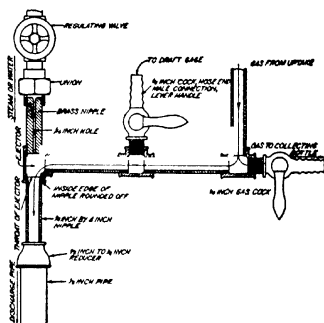
the gases. In a B. & W. boiler the sampling pipes can be thrust through the top blow-hole at the last pass. In a Heine boiler the pipes can be run through one of the hollow stay bolts. In a return-tubular boiler the top handle can be removed from the boiler doors. Place the tube 6 in. from

Water-tube boiler   Fire-tube boiler
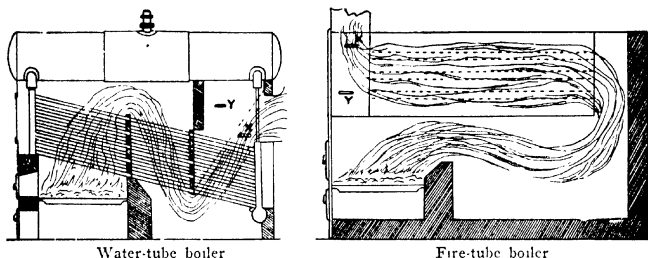
LOCATION OF FLUE-GAS SAMPLING TUBES—*Hays*

X = Proper.   Y = Improper.

the boiler head and above the top row of tubes If it is put in too far, it may come into a dead space. Be sure to get none of the air leakage around the doors. If air leaks in at the rear arch, most of it will find its way through the upper tubes. *Hays* also recommends in taking gas samples from the first pass to be sure that the fire is in good condition. If the opening of the sampling tube is immediately above an air hole, low CO_2 will be reported, whereas the actual average from the furnace may be high.

Where it is impossible to obtain analyses directly from the boiler every few minutes and it is desired to secure an average sample over a given period, a collector can be used. A form suggested by the *Bureau of Mines* and consisting of two water bottles is shown in Fig. B, p. 249. It is connected through a gas filter to the aspirator. The water from the upper bottle is syphoned into the lower one, drawing the gas into the upper. For collecting samples over a period of half a day, bottles of 2-gal capacity are advisable. It is suggested that all rubber connections be made of ¼-in. black seamless unvulcanized rubber tubing, of heavy walls. This tubing remains elastic, and retains gas-tight joints.

The successful operation of CO_2 recorders depends largely upon the sampling line. As *C. C. Phelps* has pointed out, flue gas is always laden with soot and dust and almost invariably is saturated with moisture, besides containing intensely corrosive sulphur impurities in small quantities. An efficient soot filter will avoid fouling the CO_2 machine and permit the use of a smaller bore sampling line, which decreases the time lag. Two types of filters have been used. One, made of porous refractory material which will pass the gas but exclude dust and soot, is placed within the hot setting at the intake end of the gas sampling line. The heavy deposit of soot on such a filter does not interfere with gas flow, because the soot deposited is in itself an excellent filtering medium when hot and dry. Such filters remain in

service for months and even years without attention. Conditions which may interfere with the proper functioning of this type of filter are the impingement of white-hot particles of ash against the filter, which may cause the pores to fill and to seal over, and second, wet steam, as from a soot blower, directed against the filter covered with cement-like ash causes a similar sealing action. With a good refractory filter it should never be necessary to blow out the line. An older and less efficient type of filter is that installed outside the boiler and filled with cloth or waste. It must be replaced frequently, and the line between it and the boiler blown out occasionally.

The sampling line must slope all the way from the end of the line in the furnace to a drain, without pockets or sagging portions. The drain must be placed at the lowest point, preferably a relatively cool spot, a U-bend filled with water being the most convenient form. The opening through wall of the setting should be large enough for removal and inspection of the filter, and the cover over this opening should hold the sampling line in position. Outside of the setting the line should be supported several inches away from the furnace walls, to give the gas a chance to cool and deposit moisture. Brass is probably the most serviceable material to use for damp flue gas. The water flowing through it will gradually corrode it, but if it is sloped the condensate will not have an opportunity to become so heavily charged with acid, so that the corrosive action will be very slow and the line will have a life of several years. In assembling the line care should be taken to remove all burrs left on the inside of the pipe, and to be sure that there is no dirt between the butt ends of the pipe in the couplings. Iron pipe is inferior to brass or copper for the reason that the iron sulphate is insoluble and will gradually build up a deposit that will close the line, even though it is well sloped. Rubber tubing is decidedly unsuitable for any part of the gas line, because rubber absorbs sulphur dioxide to a great degree and thereupon becomes brittle and cracks open. The entire line should be of one material, that is, if brass pipe is used, all fittings should also be of brass, in order to prevent electrolytic action. Running a gas sampling line alongside a steam pipe or anything that retards condensation is objectionable. From the water seal, the gas should pass through a gas drier employing calcium chloride. It is desirable to keep the brine formed from the latter separate from the acid condensate by providing a seal pot on the drier for reception of the brine. Water jacketed condensers are not as good as calcium chloride driers, as the water supplied may be hot at times, resulting in no condensation. Sulphuric acid is formed in the flue gas in small proportions from the burning of sulphur in the fuel, and should be removed by a desulphurizer, for which purpose some CO_2 recorder manufacturers use an alundum thimble. Gas which has been properly filtered, dried and desulphurized will not discolor or rot a piece of cotton or white paper, even after flowing through it continuously for six months. If a steam or compressed air aspirator is employed, care must be taken not to connect its exhaust with the exhaust of other equipment, as this may subject the aspirator to back pressure, preventing its proper functioning. A separator should be inserted in the steam or air supply line close to the aspirator.

The *Bureau of Mines* points out that carbon dioxide is much more soluble in water than oxygen or nitrogen, their respective solubilities being approximately 90, 2 and 1. Furthermore, water from well or river is usually more nearly saturated with oxygen or nitrogen than with carbon dioxide. It is therefore easily seen that the collection of gas over water may indicate an entirely incorrect % of CO_2. If the analyses of the gases

in question were always the same, the water would become saturated with CO_2, and would neither give up nor absorb CO_2. Experiments show that a brine solution will absorb CO_2 less readily than will water. A 10% solution is effective, but a saturated solution is better This saturated solution is made up of about 3 5 lb. salt to 10 lb. of water. If the % of CO_2 does not vary more than 2 or 3%, and if the gas does not stand over the liquid more than 2 hr., water may be used satisfactorily as the confining liquid. Brine may be used to advantage for gases that have a greater variation than 3% of CO_2, and that are held more than 2 hr. over the liquid. Flue gas should be analyzed as soon as collected. Shaking of the liquid and any change in the temperatures should be avoided. Ordinarily when collecting flue gases in the boiler room, it is doubtful whether the % of CO_2 of the collected gas when analyzed is closer than $\frac{1}{2}$% to the gas as it enters the collection bottle. It should also be noted that with the ordinary arrangement the gas is drawn into the sampling bottle uniformly with respect to time and not in proportion to the load. If the load varies much, such samples are of little value.

FLUE GAS ANALYZING APPARATUS

There are several types of apparatus for analyzing flue gas. The **Orsat**, which is representative and most widely used, will be described. The diagram and description are due to the *Bureau of Mines*. The essential parts of the apparatus are a measuring burette, three absorption pipettes, a leveling bottle and a header, all of glass. The measuring burette ordinarily contains 100 c.c., and is graduated in 100 units, each unit being graduated into fifths. It is usually enclosed in a water jacket, which prevents sudden temperature changes while the analysis is being made. The pipettes are U-shaped glass vessels; and contain solutions for absorbing the gas constituents. The first one contains caustic potash solution for absorbing the CO_2 The second one contains an alkaline solution of pyrogallic acid for absorbing oxygen, while the third contains an ammoniacal solution of cuprous chloride, for absorbing the carbon monoxide. The side of the pipette in which the absorption is to take place is filled with small glass tubes, which increases the surface of liquid in contact with the gas. The pyrogallic acid solution and the cuprous chloride solution absorb oxygen readily. Air must be kept from coming in
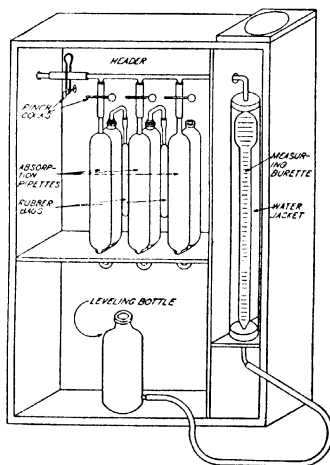
ORSAT APPARATUS

contact with them. A rubber bag is placed on the rear side of both these pipettes, or a water-seal consisting of a fourth pipette is used. The gas is drawn into the burette and forced out of it by means of a leveling bottle attached to the lower end of the burette by a 3 ft. rubber tube. The leveling bottle also permits regulation of the pressure on the gas. The header connecting the burette and the pipette is made of ¼-in. glass tubing. Each outlet is sometimes fitted with a ground glass cock, but such cocks require constant attention to prevent them from sticking and leaking. Pinch-cocks on the rubber tubing are as satisfactory.

PREPARATION OF SOLUTIONS

The solution for CO_2 absorption is caustic potash, or potassium hydroxide, KOH. The solution should contain 330 grams of potassium hydroxide for 1000 c c of water This is about 14 oz dissolved in 61 cu. in. of water, or 1 lb. of caustic to 2 5 lb. (2½ pints) of water It can be made in an open vessel, and when cool poured into a bottle for storage. If a precipitate forms, which is usually the case, only the clear liquid should be used. This solution will fill a pipette about 5 times, and each pipetteful can be used for about 150 determinations.

For absorbing oxygen, the solution is prepared by dissolving 10 grams (about ⅓ of an ounce, or 2½ cu. in.) of pyrogallic acid in 25 c.c. (about 1 fluid ounce, or 2 cu. in.) of water. This is poured into the pipette, and potassium hydroxide solution from the caustic stock bottle added until both arms of the pipette are a little more than half full The two solutions should be mixed in the pipette and the seals attached immediately in order to prevent oxygen absorption from the air The mixing is done by raising and lowering the leveling bottle a few times, which draws the gas. Light causes a deterioration of this solution

The solution for absorbing CO can be prepared best in a two-quart bottle. To 750 c.c. (about 25 fluid ounces, or 46 cu in.) of water in the bottle is added 250 grams (about 9 ounces, or 30 cu. in.) of ammonium chloride. The mixture is shaken until the crystals are dissolved, which is accomplished quite readily. To this solution is added 200 grams (about 7 ounces, or 12 cu. in.) of cuprous chloride The chloride dissolves slowly, and the mixture should be shaken from time to time. All of the cuprous chloride may not dissolve. When the solution is being used, only the liquid should be poured off, without disturbing the sediment. A few pieces of scrap copper should be placed in the stock bottle to keep the cuprous chloride reduced. If tightly stoppered, the solution can be stored indefinitely. In preparing the solution for the pipette, pour out enough into a graduated vessel to fill one arm of the pipette. To this quantity add slowly ammonium hydroxide having a specific gravity of 0.91. As the ammonia is first added, a white flaky precipitate forms, which disappears as the addition of ammonia continues, and the solution becomes dark blue. The mixture should be stirred well while the ammonia is being added, and the amount of ammonia should be just enough to dissolve the precipitate completely. The ratio of stock solution to ammonia is about 3 to 1. If too much ammonia is added, the vapor will increase the volume of the gas sample after contact with the solution. When new, the solution will dissolve all the CO from the gas, provided sufficient time is allowed, but

after it has absorbed considerable carbon monoxide, it will not remove it all from a gas mixture, and may even give some off. The operator must therefore know the condition of the solution, to be certain of his results. For small amounts of carbon monoxide, a solution that has not previously absorbed much can be used.

According to *J. E. Terman,* the absorption capacities of Orsat solutions are as follows:

Potassium hydroxide 40 times its own volume before it becomes too weak.

Potassium pyro-gallate, 2 times its own volume.

Cuprous chloride, its own volume of *CO.* Some authorities give higher values, but this solution is cheap, and is not very good at the best.

MANIPULATION OF ORSAT APPARATUS

Black rubber tubing should be used; it is more elastic and will maintain a gas-tight joint better than other tubes.

The pipettes should be removed from the rack for filling. The solution should fill the arms a little more than half full, and when drawn up to the thin mark on the stem of the pipette, it should stand in the rear arm to a depth of about one inch. Care should be taken not to get the solutions on the hands or clothing, as they are strongly alkaline.

There are several points which should be followed in the care and use of the Orsat. When ground glass cocks are used, they should be well lubricated with vaseline in thin films, so that they are gas-tight and will not corrode. The water in the burette and leveling bottle should be saturated with flue gas. If any of the solutions are accidentally drawn into the burette, the water should be changed. The apparatus should be kept clean. The rubber connections should be watched carefully to see that they are gas-tight, and tests for leaks should be made every day before an analysis is done. All measurements of volume must be made under the same pressure. This is accomplished by means of the leveling bottle. Changes in temperature during the analysis should be avoided, as they introduce error.

The apparatus should be tested for air leakage. To do this, the burette is filled about half full with air, and all the stop-cocks closed. The leveling bottle is lowered two or three feet, the air inside being thus placed under a reduced pressure. If the water in the burette falls to a certain point and then remains stationary, there is no leak, but if it continues to fall slowly, there is a leak, which must be stopped before the analysis is undertaken.

The manipulation of the Orsat apparatus consists of two operations, moving the gases into the different parts of the Orsat, and measuring their volumes. The moving of the gases is done with the water in the leveling bottle, which acts as a piston. The Orsat is connected to a source of gas supply, such as the collector bottles, or the gas pipe to the aspirator, usually through some form of filter. By raising or lowering the leveling bottle and opening the cocks to the absorption pipettes in turn, the level can be adjusted to the mark on the neck of the pipette. With the burette filled with water, opening the cock in the gas supply line and lowering the leveling bottle will draw a charge of gas into the Orsat. The cock in the

gas supply line should then be closed and the cock to the atmosphere opened, and this quantity of gas rejected to the atmosphere by raising the leveling bottle. This should be done two or three times to remove all the air and residual gas from the Orsat apparatus, after which a charge is retained for analysis. A delicate means of adjusting the flow of water from the bottle is to pinch the rubber tubing in the hand. The quantity of gas is accurately measured to 100 c.c, by adjusting the level in the leveling bottle and in the burette to the zero mark on the graduation, releasing some of the gas from the system. It is essential in all volume measurements that the level in the burette and in the leveling bottle be the same.

The cock in the caustic potash pipette is opened and the leveling bottle raised, forcing all of the gas into the pipette until the water level stands in the neck of the burette. The gas is passed between the burette and the pipette two or three times, and then measured. It should then be passed into the pipette and again into the burette and remeasured in order to be sure the CO_2 has been entirely absorbed. The difference in volumes before and after absorption is the amount of CO_2 in the sample, and as the sample was originally exactly 100 c.c., it is the % CO_2 in the gas. The oxygen and the carbon monoxide are determined in the same way by passing the residual gas successively into the remaining pipettes. The CO_2 and the O_2 must be completely removed before attempting to determine the CO. After any one of the absorptions, before the measurement, the solution must be brought to the neck of the pipette.

CO_2 RECORDERS

While hand indicators, such as the Orsat, can be used as a means of studying air-supply conditions, or for occasional tests, they do not answer the purposes of daily plant operation, since the CO_2 content of the flue gases may, and does, vary widely, rapidly and continuously, due to the fact that the proportions of the total air supply which comes through the fire and in above the fire are easily upset by the throwing on of fresh coal, the burning through of thin spots, accumulations of clinker and ash, manipulation of dampers and fire doors, etc. It can hardly be said·that CO_2 recorders act promptly enough to follow the variations in CO_2 from minute to minute, but they do on the other hand produce a chart showing an average, which serves as a warning to the fireman who is careless or incompetent in his management of the fire and draft. Wherever possible, it is advisable to arrange CO_2 machines so that the gases will be drawn rapidly and in a constant stream from the furnace to a point near the CO_2 machine, and in excess of the requirements of the latter. In this way, lag in the indications of the machine, due to storage in the pipe line and filter, can largely be overcome. A filter should be installed near the point of sampling. Directions in regard to the location and arrangement of sampling pipes, as given on pages 249 to 254, also apply here.

The **Republic CO_2 Recorder** is an automatic Orsat apparatus which makes a continuous record on a radial chart, a friction holder preventing the pen from returning to zero in the intervals between analyses.
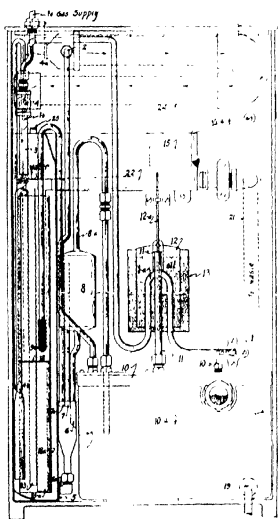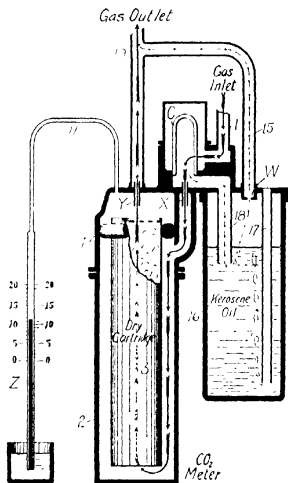
REPUBLIC CO_2 RECORDER   APEX CO_2 METER AND INDICATOR

The **Apex CO_2 Meter** registers pneumatically the reduction in gas volume caused by the absorption of CO_2 by a dry cartridge of caustic soda through which gas is continuously circulated. The sample is drawn in at *1*, passes down to the absorption chamber *2* and out through the cartridge *3* to *19*. It enters the constriction X under a fixed suction and emerges through constriction Y under a higher fixed suction, hence the only variable affecting the vacuum in tube *11* is the momentary CO_2 content of the gas passing through the instrument. A visual indicator Z and a bell recorder operating on the hydrostatic or mercury-column principle, both connected to *11*, are employed advantageously even in small plants. The unused gas is by-passed through *18* and the constriction W, the air bubbler *17* preventing excessive suction. The renewable cartridge is good for a life of 1200 %-hours. A refractory filter disc is used at the end of the gas sampling pipe inside the setting, followed by a calcium chloride dryer, which permits the use of small pipe and high sampling velocity.

In the Foxboro-Heath CO_2 Recorder, the CO_2 is absorbed by a caustic solution, the amount of the residual gas being indicated by an oil-actuated float. The flue gas is drawn by the aspirator *18* through the filter *20* into gas bulb *5* to the right, and forced to the left chamber, where it bubbles through the caustic *7* and the layer of oil floating on top of the latter. The oil is in communication with the float tube *10*, the level in the latter depending upon the amount of gas collected above the oil in the lower chamber, and the CO_2 is indicated by a dot of the pen on the clock-driven chart. The instrument is operated by the syphoning action of water, which by flowing through the coils also tends to equalize the temperature, about two barrels of water being required per day. Up to 30 analyses per hour can be made, and all delicate parts are protected from contact with the caustic
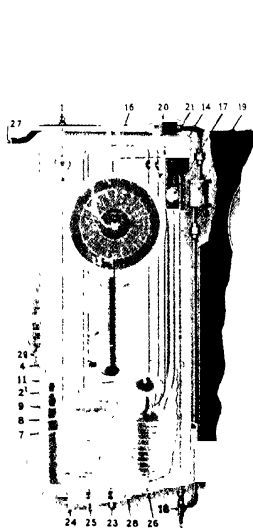
FOXBORO-HEATH CO_2
RECORDER
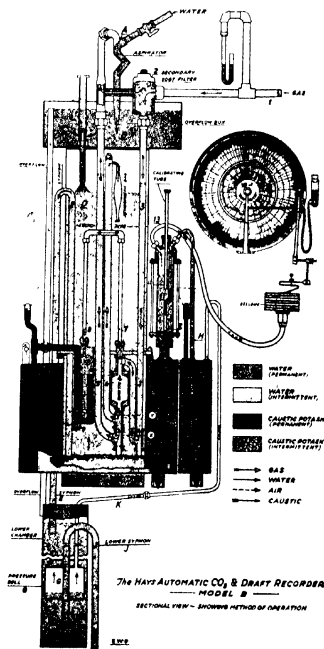
HAYS CO_2 AND DRAFT RECORDER

The Hays Automatic CO_2 and Draft Recorder is a water-driven Orsat. Water flows constantly into the overflow box *B* and out through

the overflow, and the aspirator A draws gas to be analyzed through the secondary soot-filter 2, down through tube 3, through burette 4, and up through tube 5. Water also passes to the standpipe D through regulating sleeve C at a rate depending on the number of analyses desired per hour, and when it reaches the level X, gas flow is by-passed through the connection to the left of 2, a sample is trapped in the burette and placed under atmospheric pressure by connection through 6 with the rubber atmospheric bag under B When the water level reaches Y, the 50 c.c. sample thus secured is pushed through tube 7 to absorption chamber S, containing steel wool and KOH solution, which absorbs the CO_2 and is displaced into caustic container 10 and compression cylinder 11 The more CO_2 is present the less KOH is pushed over When enough KOH rises in 11 to seal the calibrating tube 12, air is compressed to act through the bellows and move the CO_2 pen When the operating water level reaches the top of the syphon E, the standpipe is emptied and operation repeated, the KOH returning to S and fresh gas passing through the burette. The outer ring of the chart indicates CO_2, for a range of 0 to 20%, and analyses are made every one to four minutes, an interval of $2\frac{3}{4}$ min. being recommended. The inner ring records the draft, from 0 to 1 in, and by having a record of draft over the fire and another of draft in the last pass, the draft loss, or "air flow" as it is sometimes called, is indicated by the "spread" between the two draft records The CO_2 mechanism is largely visible, temperature is maintained constant by a water jacket, and the record is guaranteed to be within $\frac{1}{2}$ of 1% of the true CO_2 percentage at any point

The Ranarex Recorder determines CO_2 through the variation in density of gas. The fan 1 in the left-hand sketch is driven at constant speed and draws in flue gas through inlet 4 and expels it through 5, while

blade 2 of the impeller gives a whirling motion to the gas in the chamber which tends to rotate the vaned disk 6 Air is drawn through a similar fan in another gas-tight compartment, and the two disks 6 are coupled together by levers A and B and a connecting link which is shorter than the center-to-center distance d. The levers take up a position in which the torques due to air and gas density balance each other, and the indicating or recording device then shows the percentage of CO_2 which has determined this position. The instrument is said to be accurate within 0.1%, and to have a time lag of only 20 to 30 sec., which is due to the neces-

RANAREX CO_2 RECORDER --
London Engg.

sity of cooling the gas sample to room temperature.
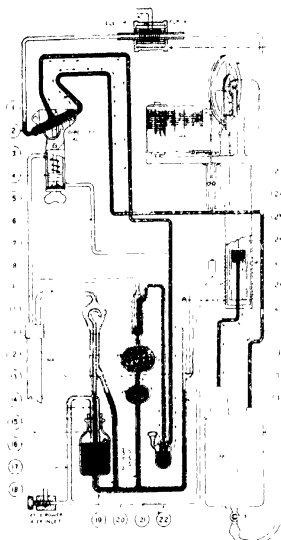
TAG-MONO DUPLEX RECORDER
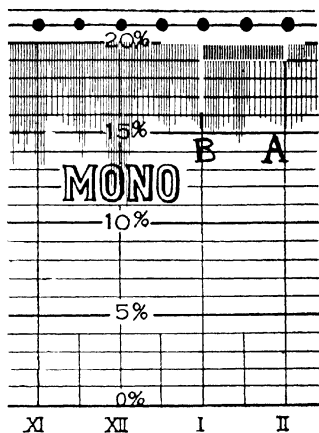
CHART FROM MONO RECORDER

The Tag-Mono Duplex Recorder has a mercury pump *16* operated by water power which draws in a gas sample, passes it through the volumeter *10* and directing valve *2* to the caustic potash tank *33*, where the CO_2 is absorbed, and the volume of the residual gases is measured in the gasometer *27* and recorded on the chart above. The valve *2* is then tilted so that the next sample passes to the electric furnace (top), where any combustible gases (CO, CH_4 and H_2) are burned to CO_2 and H_2O, by means of the oxygen present and a charge of copper oxide which supplies any necessary excess oxygen and acts as a catalytic agent. This water and CO_2, as well as the CO_2 initially in the sample, are absorbed and the analysis recorded, so that if combustible is present in the gas samples, every alternate record shows a greater apparent CO_2 than its neighbors. The bottom of each vertical line represents the result of an analysis; during a period when combustible is present, as at *A* in the sample chart, the upper part contains a series of finely-spaced lines whose lower boundary is a measure of the CO_2 plus combustible gases, while below this there is a "gray" area with alternate lines missing, the lower boundary of which indicates the CO_2 in the gas as it comes from the furnace. Such an area is a danger signal, whether CO_2 is high or low. With proper firing and draft regulation, it becomes possible, by watching the critical point, to retain a relatively high CO_2, as at *B*, and yet take care not to permit any combustible to pass off in the gas.

COMPARATIVE RECORD OF FOUR CO_2 INSTRUMENTS
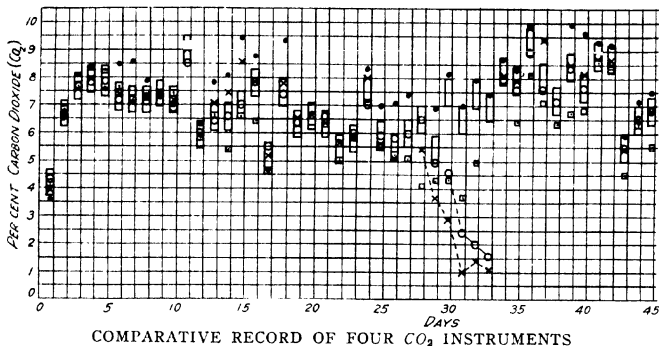
J. F. Barkley describes a test made by the *Bureau of Mines* on four of the newer types of CO_2 Recorders, including one using an electrical principle. The daily averaged records of each instrument are indicated on the chart by dots, circles, crosses and squares respectively, while the center of each rectangle (1% in height) indicates the day's average as obtained from a hand-operated Orsat; hence a plotted point falling within a rectangle indicates an accuracy within $\frac{1}{2}\%$ CO_2. The CO_2 of the boiler to which the instruments were attached was fairly high during the day, but low at night. For the first few days all the instruments gave acceptable accuracy. The low spots connected by dotted lines show the effect of intentional postponement of chemical renewals. With 50 ft. of $\frac{1}{2}$-in. gas pipe ahead of the instruments, the CO_2 was changed from 10% to zero, and the length of time required by the various instruments to show this change correctly was found to vary from 4 to 20 min. It is strongly recommended that a recorder should be operated by a man who will learn every feature of it and check it with an Orsat until he knows when it is accurate by its general working appearance, otherwise it is hardly advisable to attempt the use of such instruments.

P. E. Palmer and *E. R. Weaver* describe the investigations of the *Bureau of Standards* on thermal-conductivity methods of gas analysis, in which a comparison is made of the electrical resistance of two platinum wires, one stretched in a tube through which slowly circulates the gas under investigation, and the other in a similar tube containing a reference gas. The wires, connected to a source of constant emf., are cooled mainly by conduction of the nearly-stationary gas jackets, and attain equilibrium temperatures (hence resistances) depending on the relative thermal conductivities of the two gas mixtures. Such devices, when calibrated, can be used to check the results of a wide variety of industrial processes, as for the determination of oxygen in electrolytic hydrogen, hydrogen in water gas, ammonia in gases from synthetic-ammonia plants, etc. In some cases the gases are subjected to chemical reactions before or after passing through the instrument, but the CO_2 content of flue gases is determined without special treatment. With an unbalanced Wheatstone bridge, which
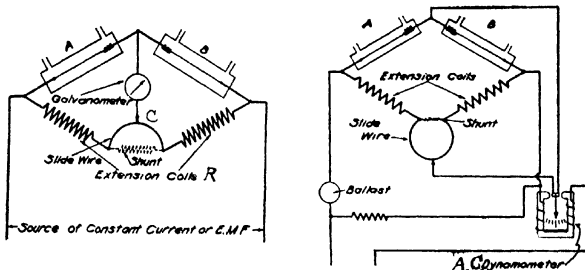
THERMAL CONDUCTIVITY GAS ANALYZER, BALANCED WHEATSTONE
BRIDGE TYPES—*Bureau of Stds*

is like the left-hand figure, except that a fixed connection is used instead
of the slide-wire and shunt shown, the platinum wires in the gas-tubes A
and B form two arms of the bridge, while the two fixed resistances R
form the other two arms, and the deflection of the galvanometer indicates
the variations of resistance in A and B. A potentiometer can be used in
place of the galvanometer. In the balancing type of bridge, the contact C
is moved along the slide wire until the galvanometer reads zero, the slide
wire being calibrated in terms of gas composition. With the use of an
A.C. galvanometer, an A.C. lighting circuit can be employed. The
authors give, in the table below, the results of their experience with this
and other types of gas indicators, and state that when incorporated in
automatic recorders, the advantages of thermal-conductivity apparatus
over devices employing density or volumetric measurement are still more
pronounced.

ESTIMATED RELATIVE ADVANTAGES OF VARIOUS METHODS OF
OBSERVING GAS COMPOSITION[1]

Desirable Characteristics	Thermal conductivity	Interferometer	Density balance	Direct weighing	Chemical separation and volumetric determination
Sensitivity	1	2	5	4	3
General applicability	3	2	5	4	1
Independence of physical conditions difficult to control	2	1	3	5	1
Independence of calibration	5	4	3	2	1
Time lag	1	2	3	5	4
Time required of observer	1	2	3	5	4
Fatigue of observer	1	5	2	3	4
Skill required of observer	1	4	3	5	2
Computation required	1	4	3	5	2
Probable error of observation due to personal equation	1	4	3	5	2
Amount of gas required	1	4	2	5	3
Probable cost of apparatus	3	4	2	5	1
Probable cost of continuous operation	1	4	2	5	3

[1]The method possessing the greater advantage is given the smaller number.

The Leeds & Northrup CO_2 Recorder employs a Wheatstone bridge recorder operating on the null principle, its accuracy being unaffected by slight changes in the bridge current supplied from a 4-volt 40-amp. lead-plate storage battery, which can be charged by a rectifier and transformer.
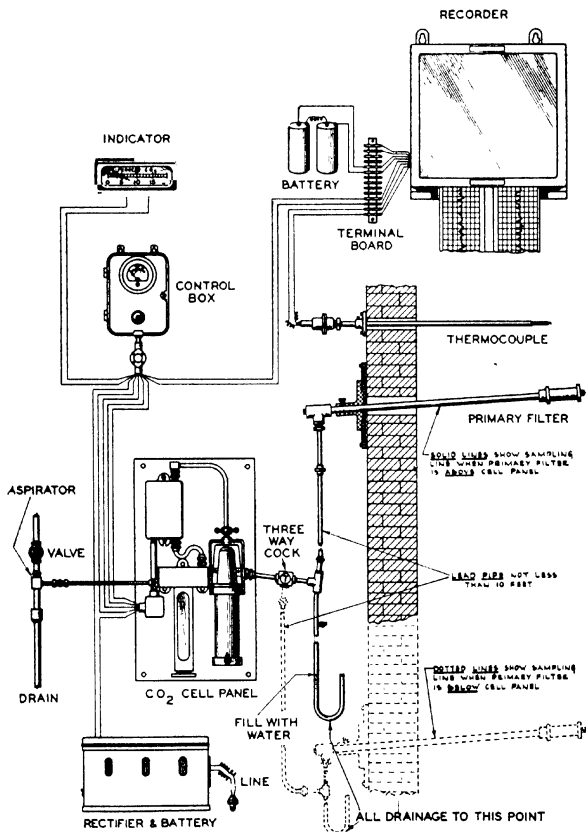
LEEDS & NORTHRUP CO_2 METER
WITH INDICATOR AND RECORDER, COMBINED WITH
RECORDING PYROMETER

The primary filter is a porous cylinder mounted on a ½-in. iron pipe, while a calcium chloride drier and a porous earth thimble remove any remaining dirt, moisture or acid mist from the gas before it goes to the gas-cell unit The rate of flow of the gas through the latter is constant and independent of the rate of flow in the sampling line The recorder accuracy is ½% of the range of 20% (CO_2, or 0.1% CO, while the overall accuracy is better than 0.5% CO_2 Each chart division of 1% CO_2 is about ½ in. long The potentiometer recorder can be made to record gas temperature, rate of steam flow or other variables on the same chart

In the Bacharach Electric CO_2 Meter a sample is drawn through the tube A to the cooler B, in the outer jacket of which circulates water going to the aspirator G, then to the soot filters C and E, through the tester and to the aspirator G Cocks 2 and 3 are adjusted to produce a suction of about ½ in , for a flue draft of 1 in the manometer F should indicate 1½ in water column Referring to the enlarged view of the tester, immediately above and below the main gas chamber are shown two small chambers through which a portion of the gas flow takes place, and which contain small platinum wires The upper block has similar chambers and wires containing air at room temperature, and the four wires form the four branches of a Wheatstone bridge circuit, with a galvanometer connected to the "mid-points" and calibrated as a CO_2 indicator Energy is obtained from a storage battery M, adjustment for constant current being made by variable resistance 1 The N_2, O_2, and CO in the flue gas have practically the same conductivity, the moisture content thereof is small and constant, and the comparison air is dried by hydroscopic material in 5, hence any variation in conductivity depends on the CO_2 in the flue gas, CO_2 having 40% less conductivity than the other gases The slowly-moving flue gas in the lower chambers transmits heat from the wires less rapidly than the air in the upper chambers, the lower wires therefore become hotter than the upper, their resistance increases, unbalancing the circuit and causing a deflection of the galvanometer indicator depending on the amount of CO_2 present The interval between the drawing of the gas sample and indication of its CO_2 content does not exceed 2 min , and the accuracy is guaranteed within ±½% of CO_2 An automatic recorder can be employed in addition to the indicator
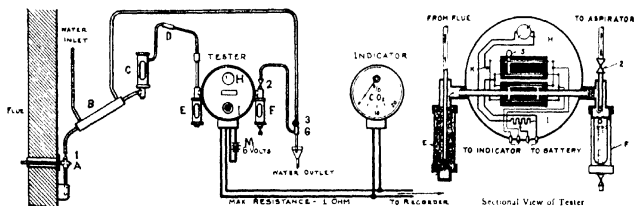
BACHARACH ELECTRIC CO_2 METER

In the **Brown Electric CO_2 Indicator or Recorder** the gas sample is taken through a condenser and a renewable cloth soot filter, then through

a steel-wool filter to the thermal-conductivity cell. When D. C. is available, the storage battery floats on the line in series with several lamps, or with A. C. a battery charger is supplied. An indicator or recorder can be connected in turn to different boilers by a switch. Records are made on 45-day rolls, or on daily circular charts, and can be combined with the record of a sensitive thermocouple. Accuracy is $\frac{1}{2}\%$ CO_2, and the electrical system shows a change in CO_2 as soon as gas enters the cell.

CO_2 INDICATORS

PLAN

ELEVATION
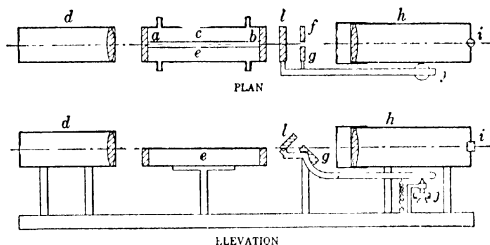
PRINCIPLE OF INTERFEROMETER, LABORATORY TYPE

For making CO_2 determinations at frequent intervals the *Bureau of Mines* has used the **Haber-Lowe Interferometer**, which utilizes the fact that the refractive power of a gaseous mixture varies according to the composition. A portable type, about 4 in. in diameter and 20 in. in height, has an accuracy within 0.2 to 0 3%, comparable to that of an Orsat. The laboratory type has an accuracy of .02 to 03%, precision equal to that of an analyzer operated by mercury. The entire apparatus, illustrated in the above sketch (which is not to scale) is about 6 ft. long, the gas tubes c and e occupying half this length. Light enters from a Nernst lamp mounted immediately to the left, and passes through a collimator d, from the slit of which parallel rays emerge, and travel in three parts to the telescope h, where an image of the slit is produced, with interference bands, which appear as two straight parallel dark bands in the white field, with colored bands on both sides. The upper half of the beam passes through the open air above the tubes c and e. Plate l serves to deflect the pencil downward and to blot from the field the dark band caused by the thickness of the metal tubes that confine the gases. This pencil of rays passes through the diaphragm to the upper half of the object glass of the telescope. The lower half of the pencil of rays is divided into two equal parts by the metallic partition ab between the chamber c and the chamber e for the gas used for comparison. The compensator plate f is fixed, while g can be moved by a micrometer screw, thus varying the optical path of the chamber e. When c and e are filled with standard gas containing none of the constituents to be tested for, but otherwise similar in composition to the sample, and the compensator plates are perfectly parallel, the interference effects of the lower half cannot be distinguished from those of the upper. If, however, some other gas, as air mixed with

CO_2, is introduced into c, the lower band image is shifted laterally. The plate f is then turned by the screw j until the two effects are similar, the number of turns being a function of the composition of the gas. While the relation can be figured on theoretical grounds, in practice the instrument is calibrated by comparison with direct analytical results. The gases tested are dried by sulphuric acid, and are passed through the tubes until the effect on the bands becomes constant. They are in communication with the atmosphere by capillary tubes at the ends, which maintain atmospheric pressure without permitting diffusion. The interferometer can be used for determining CO_2 in furnace gases only where the combustion is very nearly complete; in other words, where neither CO nor H_2 are present in the gases. In the chart at the top of page 156, the instantaneous, non-averaged results from an interferometer are compared with those from an automatic CO_2 recorder.
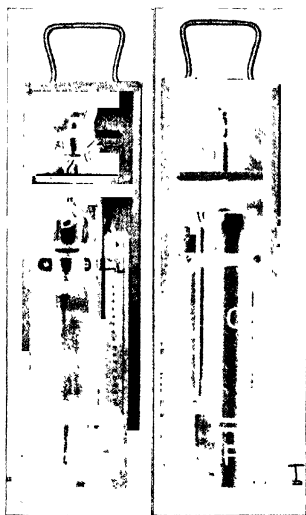
BUREAU OF MINES CO_2
INDICATOR
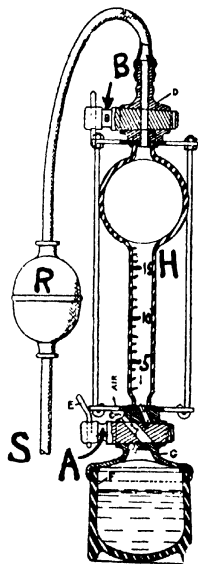
BACHARACH
CO_2 INDICATOR

The *Bureau of Mines* has devised a portable CO_2 indicator which can be used by a layman. Gas is drawn from the stack through a tube T by means of a hand bulb (not shown) and forced through an asbestos fiber filter F and a cooler C (consisting of copper tubing surrounded by a water jacket) and out through a ball valve in the top of the humidifier H, which is filled with moist cheesecloth. Four or five slow squeezes on the bulb fill the cooler and humidifier with gas. The needle valve N on the left leg of the apparatus is then opened and the operator blows into the rubber tube R affixed to the right leg until the solution (which normally stands at the level L in both legs) rises in the left leg to the bottom B of the capillary tube. The rubber tube is then released, and the level returned to normal, drawing in a sample of gas through the needle valve. This is repeated, and with the levels at L the needle valve is closed, the rubber tube pinched and the instrument shaken up and down vigorously for about a half minute. The tube is released and the indication read on the scale. The tube is then pinched again, and the apparatus shaken and if the second indication is the same as the first, it is the percentage of CO_2 in the flue gas, but if it has changed appreciably, the operation is repeated until the indication is constant. The solution is a comparatively dilute one, made by dissolving 10 grams of electrolytic stick sodium hydroxide, $NaOH$, in 100 c.c. of water, and has a specific gravity of 1.11 at 15° C. Fresh solution should be used when the rate of absorption becomes slow, or when enough suspended matter has gathered in the liquid to interfere with the operation of the indicator. The solution is covered with a layer of 32.5 c c. of white oil, such as "Nujol," to prevent premature absorption, the perforated glass projection P serving to prevent migration of the oil to the wrong leg. The indicator is accurate within ± 0.5% of CO_2.

The Bacharach American Pocket CO_2 Indicator is shown on p. 267. In making an analysis, the lower valve A is opened to atmosphere, and gas from source S pumped through the glass tube H by the rubber bulb R. The upper valve B is closed, and the lower opened to connect with the KOH solution below, after which the device is tilted back and forth until the CO_2 is absorbed. The KOH is then shut off, and the instrument inverted with the valve B under water. B is opened, and closed when the water reaches the same level, inside and out, indicating that the residual gas is under atmospheric pressure. On reversing, the CO_2 originally present is indicated on the scale by the height of the column of liquid. The maximum error is said to be 0 2%.

WHAT CO₂ INDICATES

The CO_2 indication serves as a means of first approximation. After the CO_2 has been brought up to the required % the CO determination should be made. As pointed out by *Steam*, while high CO_2 indicates a small amount of excess air, it does not necessarily mean a correspondingly good combustion. 1% of CO in the flue gas would be a negligible indication of the quantity of excess air, but might mean 4½% loss due to incomplete combustion.

Low CO_2 may be caused by excess air, insufficient air (which results in high CO) or improper mixture of the air and gases, but a surplus of air is the cause in almost every instance. The difference between the CO_2 percentages in the last and the first passes indicates the air leakage in the setting

CO_2 is also affected by the character of the fuel. The more hydrogen in the fuel, the less CO_2 in the flue gases. If the fuel were all carbon, the theoretical maximum would be 21% CO_2. If all hydrogen, there would be no CO_2 in the gases.

Hays warns against attempting to secure high CO_2 by cutting down the draft only. High CO_2 can be obtained, he says, with any draft in reason, either high or low, provided the draft and the fuel and the fuel resistance are in proper relation. CO_2 percentage indicates the ratio of the air used to the air that has not been used. It is sometimes feared that 8 or 10% CO_2 cannot be obtained without CO in considerable quantities. This is not in accordance with his experience. He does not consider that there is danger from CO until about 15% CO_2 is reached. It is assumed for the above statements that the setting is tight, and that there is sufficient draft. *Bureau of Mines* tests, on the other hand, show considerable percentages of CO with CO_2 running from 8 to 10%, in fact it is said to be difficult to average 12% CO_2 in hand-fired boilers without getting CO

A. V. King has prepared the following table to show the losses occasioned by excess air, also the characteristic appearance of the fire in connection with different CO_2 percentages

% CO_2	Unnecessary excess air %	Fuel loss, % compared with best practice	Loss on 1000 tons coal at $3.00 per ton	Color of fire	Approx. temp. corresponding ° F.
14	...	..	.	Bright white	2600
13	11	1	$30 00	White	2200
12	20	2	60 00	... ..	....
11	40	3	90.00	......	....
10	60	5	150 00	. . .	....
9	82	7	210.00	Light orange	1750
8	112	10	300.00	.... .	....
7	148	13	390 00	Bright cherry	1400
6	197	17	510.00	......	....
5	266	23	690.00	Dull cherry	1150
4	370	32	960.00	......	....
3	442	47	1410 00	Dull red	1000
2	885	77	2310 00	Dark red	900

Fig. A, by *C. J. Tagliabue Co.*, gives the heat loss in flue gases, with varying temperature and CO_2, but no CO, for a coal of the analysis indicated.
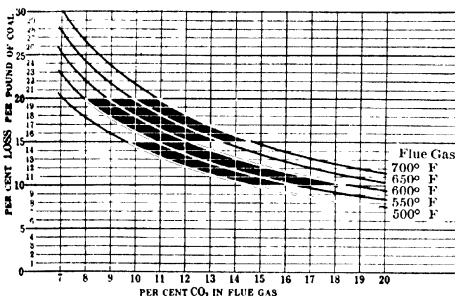
Coal Analysis:

Carbon	79.9%
Hydrogen	5.0
Oxygen	4.3
Nitrogen	1 8
Sulphur	1.2
Ash	7.8

14,351 *BTU per lb.*

A. HEAT LOSS IN FLUE GASES

See following sections, also under "Carbon dioxide, significance" in Index, for further data regarding interpretations of CO_2 records.

A. Bement gives a series of curves on page 271, which shows the relation of firing to the % of CO_2. In each case % of CO_2 is plotted against time.

In Chart *a*, condition *A* represents a dirty fire, while condition *B* represents a clean fire. This is with hand firing.

Chart *b* is for a sloping grate stoker with a dump grate at the rear. CO_2 dropped when the fire was cleaned, but recovered as soon as the dump grate was closed. Poking the coal down from the hopper resulted in so much volatile being distilled off that it did not burn. The CO_2 recovered as soon as the coal had burned to normal. It had been considered that poking down the coal after cleaning was a good thing.

Chart *c* represents the good practice in hand firing. The CO_2 rises to a certain point after the fresh coal is fired. It drops away gradually as the fire burns away. The second firing shown is better than the first, as the CO_2 is higher and continues longer.

Chart *d* also represents hand firing. The fire was full of holes, admitting excess air. When the pile was leveled with the rake, the openings were closed and the CO_2 immediately built up.

Chart *e* represents the work of two different firemen in hand firing. When *A* added coal the CO_2 dropped slightly, because he dumped the coal with little or no care. *B* broke his coal properly and spread it carefully, and the CO_2 rose slightly with each firing.

Chart *f* is for a chain grate stoker. Many firemen think there is no harm in letting the coal get low in the hopper provided it does not go below the gate.

Chart *g* shows the result of letting the fire get short on a chain grate, and the recovery of CO_2 when the fireman winds up the grate.

Chart *h* indicates the advantage of being able to ascertain what has happened when accidents occur. At 3 P. M. the bridge wall failed. This was due to excessive temperature, which is indicated by the high CO_2.
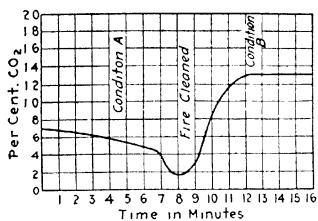
a—Dirty vs. clean fire, hand firing
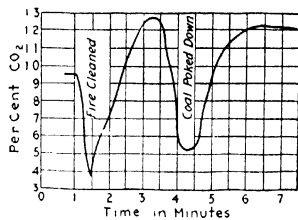
b   Sloping grate stoker
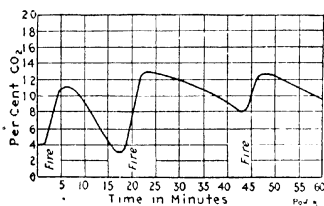
c—Good hand firing
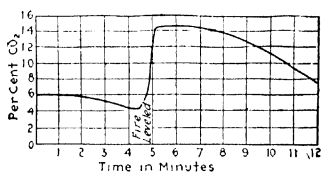
d—Effect of leveling fire
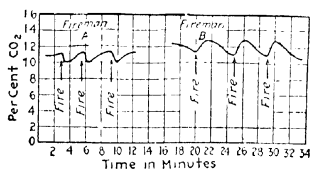
e—Work of different firemen
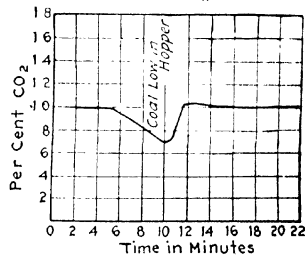
f   Low coal, chain grate stoker
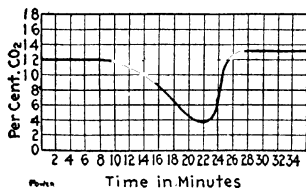
g—Short fire, chain grate stoker
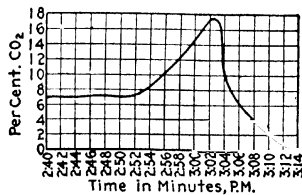
h—Cause of accident

EFFECT OF INTERVAL AND METHOD OF FIRING ON CO_2

—*Power.*

WHAT *CO* INDICATES

COAL ANALYSIS

C	79.9 %
H	5.0 %
O	4.3 %
N	1.8 %
S	1.2 %
ASH	7.8 %

14,351 B.T.U. per LB

OIL ANALYSIS

C	84.0 %
H	12.7 %
O	1.2 %
S	0.4 %
N	1.7 %

20,050 BTU per LB

HEAT LOSS AS INDICATED BY *CO₂* AND *CO*
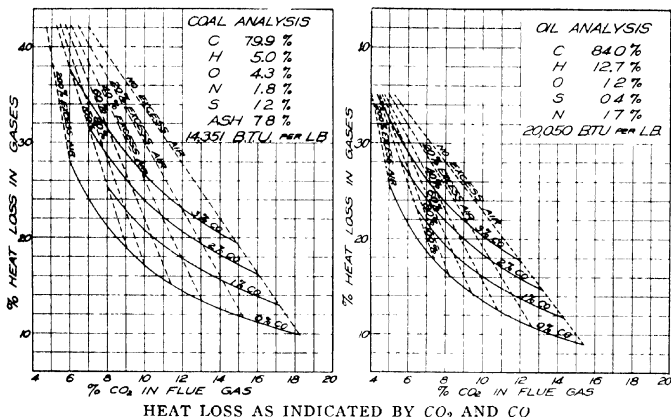
F. D. Harger gives in the accompanying three figures, the % heat loss in sensible heat of flue gases and unburned *CO*, for flue gases from fuels of the analyses indicated, escaping at 500° F. above furnace-room temperature, for various quantities of *CO₂* and combustible in the flue gases.

NATURAL GAS

CO	0.4 %
H₂	1.8 %
CH₄	93.3 %
C₂H₄	0.3 %
H₂S	0.2 %
O₂	0.4 %
CO₂	0.2 %
N₂	3.4 %

The formation of *CO* is due to:
1. Furnaces of poor design,
2. Improper methods of firing,
3. Character of fuel, particularly with reference to the equipment with which it is burned,
4. Deficient secondary air supply,
5. Improper mixing of the combustible gases with the secondary air,
6. Low furnace temperature, so that the gases are cooled below the ignition point.

The formation of CO is generally due to insufficient air supply, which, as pointed out by the *Bureau of Mines,* may be either local or general. Either the local or general cause may be from the composition of the coal. The coal may be fusible, in which case the surface of the fuel forms one solid layer of semi-liquid fuel, which effectively stops the passage of air. At the same time, a large excess of air may be fed into the furnace elsewhere. The same local excess or insufficient air supply may be caused by the fusion of ash on the grates. The volatile matter may be driven off so rapidly after a fresh charge of coal that the average air supply is not sufficient, whereas a couple of minutes after firing it is too large.

According to *A. Bement* the occurrence of CO in the waste gases is a decided danger signal, not so much on account of the loss which it represents, but because it is usually accompanied by unconsumed hydrogen and hydrocarbons. The formation of CO is a loss of small magnitude (rarely over 1% of the heat value of the fuel), yet as it may be determined easily, while the escaping volatile cannot be determined by any practicable means, the more or less general belief is that CO is a gage of the entire incomplete combustion loss.

Hays says that CO may occur with any % of CO_2. Suppose that the fire is very thick, and perhaps dirty, in one portion of the furnace. This would result in CO, because the thick and dirty part would not receive enough air. Suppose that there were an air hole at another point. Excess air would go through, and here would be CO in the flue gases in the presence of an excess of air and low CO_2.

CO occupies twice the volume of the oxygen entering into its composition. The sum of the % of CO_2 and oxygen and half the % of CO should have the same ratio to the nitrogen in the flue gases as the oxygen to nitrogen in the air supplied, viz., 20.9 to 79.1.

This takes no account of the hydrogen in the fuel. Hydrogen in the volatile constituents of a fuel leads to an increase in the apparent percentage of nitrogen in the flue gas. This is due to the fact that the water vapor formed by the combustion of hydrogen condenses at the temperature of the analysis, while the nitrogen which accompanied the oxygen remains in gaseous form.

The ordinary analysis with the Orsat does not consider other combustibles than CO.

Figured on the total heat value of the fuel, 0.1% CO in the flue gases means 0.47% heat loss, 0.1% hydrogen in the flue gas means 0.48% loss, 0.1% CH_4, 1.52% loss. In 48 tests at the St. Louis Fuel Testing Plant of the *Geological Survey,* as the CO increased from 0.3 to 0.7%, the efficiency dropped from 65 to 57%. This was a 2% drop for each 0.1%, or 4 times the theoretical amount. The hydrogen and methane were not determined. The conclusion was reached that at least two-thirds of the large drop in the whole boiler efficiency with the rise of CO was due to incomplete combustion losses not represented by CO, so that high CO is a decided danger signal. Other *Bureau of Mines* results are shown in the chart on page 274.

Sufficient CO in the gases may cause an action known as secondary combustion, the CO igniting with air in the flues or in the stack, with a resultant loss of heat and overheating of the flues and stack.

The direct heat loss due to CO in the combustion gases can be computed from the data on pages 591 or 595.
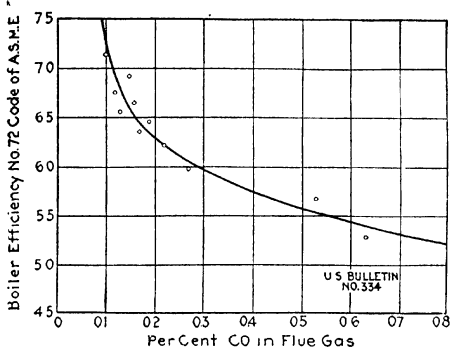
RELATION OF AVERAGE CO TO BOILER EFFICIENCY

—*Power.*

AIR REQUIREMENTS AND SUPPLY

The *Bureau of Mines* states that for every combination of furnace, coal and method of firing fuel, there is some minimum value beyond which it does not pay to reduce the air supply. Very few boilers are operated dangerously close to this limiting value. The majority of them are operated with too large an excess of air.

Due to imperfect mixture of gases, if every particle is to have sufficient air for combustion, some particles will have more than the theoretical amount, but complete combustion of the coal in the boiler furnace can be obtained with not more than 40% excess air. So long as the fire bed is level only about 7 lb. of air per lb. coal can be forced through the fuel bed. A thick fuel bed is preventive of excess air only insofar as it prevents the formation of holes. When the fire is thick or dirty, only a small amount of air flows through the fuel bed and therefore the coal gasifies at a slow rate. On account of the high resistance of the fuel bed the draft in the furnace increases and draws a larger quantity of secondary air into the furnace (through the fire door, leaks, etc.) than is needed to burn the small quantity of combustible gas arising from the fuel bed. Clinkers on the grate will also reduce the rate of combustion and increase the excess of air.

Low CO_2 may be caused by fused ash on the grates, parts of the fire being turned up by the slice bar, so that the ash on top of the incandescent coal melts. The ash may melt due to the furnace temperature being too high because of ignition arches and tile on lower row of boiler tubes. The remedy is to expose the lower row of tubes or shorten the combustion arch. The low fusion point of ash may be due to mixture of coals.

The *Bureau of Mines* states that with high-ash coals, a high draft is required. This will necessarily increase the leakage of air through the setting, so that the flue gas analysis may show a high air excess.

Air in excess of the required amount dilutes the gases and carries heat up the stack, and irrespective of the heat loss in the dry chimney gases, excess air is likely to cause furnace losses due to incomplete combustion, on account of the lower furnace temperature.

To estimate roughly the % *of excess air* from the % of carbon dioxide, subtract the observed % of CO_2 from 20.7, divide the remainder by the observed % of CO_2, and multiply by 100. Roughly, there is 1% of fuel lost for every 12.1% of air above 38%.

If the analysis of the *fuel* is known, the weight of air required to burn 1 lb. of combustible can be computed from the *Bureau of Mines* formula:

$$Lb. \ air = 11.52C + 34.56 \left(H - \frac{O}{8} \right) + 4.32S$$

C, H, O and S are fractions by weight of these elements in coal, free from moisture and ash.

The ratio of the air supplied to the air theoretically required is found by the formula:

$$R = \frac{N_2}{N_2 - 3.782 \ (O_2 - \frac{1}{2}CO)}$$

N_2 = fraction of nitrogen in the flue gas,

O_2 = fraction of oxygen in the flue gas, and is that amount of oxygen in the air supplied which has not been utilized in combustion,

CO = fraction of carbon monoxide in the flue gas.

According to the *A.S.M.E.* Code, the gases per lb. of dry coal

$$= \frac{[11CO_2 + 8O_2 + 7 \ (CO + N_2)] \ (C - C_r)}{3 \ (CO_2 + CO)} \ lb.$$

CO_2, O_2, CO and N_2 = fractions of constituents in flue gases by volume,

C = fraction carbon in dry coal,

C_r = carbon in refuse, as fraction of dry coal burned.

Since $CO_2 + O_2 + CO + N_2 = 1$, this can be written:

Weight of gases per lb. of dry coal

$$= \frac{(4CO_2 + O_2 + 7) \ (C - C_r)}{3 \ (CO_2 + CO)}$$

The table on page 210 gives weights of gases per 10,000 *BTU* for different CO_2 contents. (See also pages 137, 210, 231, 278, 594, 607.)

E. H. Lockwood gives the following formulas for the interpretation of flue gas analyses, in which N_2 is the % of nitrogen by volume, found by subtracting the CO_2, O_2 and CO from 100. Other symbols are also in %.

Theoretic air per lb. of combustible $= \dfrac{18.3N_2 + 34.8CO - 69.6O_2}{0.525N_2 + 5CO + 4CO_2 - 2O_2}$ (1)

Actual air per lb of combustible $= \dfrac{18.3N_2}{0.525N_2 + 5CO + 4CO_2 - 2O_2}$ (2)

These are theoretically correct for all fuels, solid, liquid or gaseous, except producer and blast-furnace gas. (2) divided by (1) gives the ratio of air supplied to air theoretically required, identical with formula on page 275. Adding 1 lb. to (2) gives the lb gases per lb of combustible

For flue-gases containing 11.8% CO_2, 7.7% O_2, 0.2% CO, from semi-bituminous coal burnt under a boiler, (1) gives 12.7 lb air per lb combustible, and (2) gives 19.4 lb, or 54% excess air, the CO being present even with this large excess. For flue gas containing 12.5% CO_2, 0.2% O_2, 2.6% CO, from a gasoline engine, these formulas indicate an air deficiency of 4.6%, showing that the mixture was slightly overrich. A check on the accuracy of the gas analysis can be made by comparing the results from formula (1) with the following table calculated from average fuel analyses

THEORETIC AIR REQUIRED FOR PERFECT COMBUSTION

Fuel	Volatile Matter, %	Theoretic Air per Lb of Combustible
Pure carbon	0	11.6
Gas coke	2.5	11.82
Anthracite coal	6.2	12.22
Semi bituminous coal	21.0	12.65
Bituminous (Pittsburgh)	37.0	12.85
Gasoline C_9H_{11}	100.0	15.21

An alternative check is to see if the values from the gas analysis satisfy the following relations

$$CO_2 + mO_2 + nCO = k \qquad (3)$$

where the constants have the following values

	m	n	k
Pure carbon	1.00	0.60	20.9
Gas coke	0.98	0.614	20.35
Anthracite coal	0.95	0.63	19.52
Semi bituminous coal	0.91	0.645	18.7
Bituminous coal	0.88	0.652	18.4
Gasoline	0.70	0.71	14.5

Lockwood gives the following additional formulas, applicable to any fuel in which the nitrogen and sulphur are negligible, therefore including all commercial fuels except producer and blast-furnace gas, assuming that there is no free hydrogen or other combustible except CO in the flue gas. The term "hydrogen" here refers to the free hydrogen, the part requiring air for its combustion.

Dry gas per lb of comb $= \dfrac{22CO_2 + 16O_2 + 14(N_2 + CO)}{0.525N_2 + 5CO + 4CO_2 - 2O_2}$ (4)

$$\% \text{ excess air} = \left[\frac{69.6O_2 - 34.8CO}{18.3N_2 + 34.8CO - 69.6O_2}\right] \times 100 \qquad (5)$$

$$\text{Water vapor per lb of comb} = \frac{4.77N_2 - 9CO - 18(CO_2 + O_2)}{0.525N_2 + 5CO + 4CO_2 - 2O_2} \qquad (6)$$

$$\% \text{ carbon in comb} = \left[\frac{6(CO_2 + CO)}{0.525N_2 + 5CO + 4CO_2 - 2O_2}\right] \times 100 \qquad (7)$$

$$\% \text{ hydrogen in comb} = \left[\frac{0.525N_2 - CO - 2(CO_2 + O_2)}{0.525N_2 + 5CO + 4CO_2 - 2O_2}\right] \times 100 \qquad (8)$$

$$\text{Ratio of } C \text{ to } H \text{ in comb} = \frac{6(CO_2 + CO)}{0.525N_2 - CO - 2(CO_2 + O_2)} \qquad (9)$$
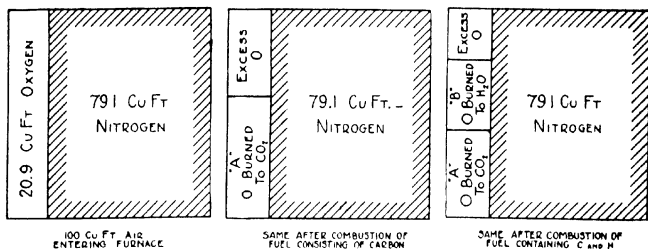
A EFFECT OF COMBUSTION ON COMPOSITION OF AIR
—*Power.*

The effect of combustion on the composition of air is shown in charts in Fig A, by *R. L. Wales*. 100 cu. ft of air passed through the furnace consists originally of the amounts of oxygen and nitrogen shown in the first square. If nothing but carbon is burned, each cu ft of oxygen so used will form a cu. ft of CO_2 when cooled to the original temperature, and the CO_2 in the flue gas will represent the oxygen *used*. The ratio of the oxygen supplied to that used will be $20.9 - (\% CO_2)$, the ratio of air supplied to air used will be the same, and the excess will be the difference. If some of the air is used to burn hydrogen or hydrocarbons, water vapor will be formed in addition to the CO_2, and the ratio of air admitted to air used will be

$$\frac{20.9}{.1 + B} = \frac{0.209[1 + CO_2(3H/C)]}{CO_2[1 + (3H/C)]}$$

Where CO_2 is *fraction* of CO_2 in gases, and H and C are carbon and available hydrogen in fuel.

G. *Herberg* gives formulas for the quantity of gases of combustion which take into account the hydrogen and water in a fuel:

$$G \text{ (in cu. ft.)} = \frac{29.89\,C}{CO_2 + CO + CH_4 + 29.89\,R} + \frac{9H + W}{0509}$$

$G =$ cu. ft. of gas at 32° F. and atmospheric pressure, per lb. coal fired

$C =$ fraction of carbon in coal actually burned (C in coal less C through grates), $H =$ hydrogen in coal actually burned (similar to above), $W =$ fraction of moisture in coal. These are by weight, based on coal as fired, while CO_2, CO, O_2 and CH_4 are fractions by volume in the flue gases. $R =$ lb. of carbon in soot for each cu. ft. of gas.

Since CH_4 and R are small and are seldom determined, the formula may be simplified to: $G = \dfrac{29.89C}{CO_2 + CO} + \dfrac{9H + W}{.0509}$

To determine the volume of flue gases at any other temperature, $t°$ F., multiply this volume G by $(460 + t)/492$.

The volume due to water and hydrogen in the coal could readily be added to the first formula giving weight of gases.
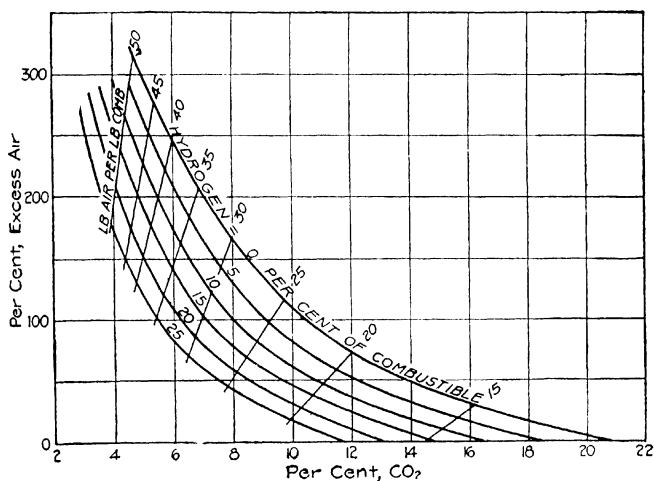
B. RELATION OF CO_2 TO EXCESS AIR, FOR FUEL CONTAINING 0 TO 25% HYDROGEN.

                                                        —*Power.*

In Fig. B, by *Haylett O'Neill*, allowance is made for hydrogen in the fuel. In burning pure carbon a percentage of CO_2 less than 21 indicates excess of air, but the hydrogen content of coal also consumes oxygen, which does not appear in the CO_2 analysis. With this chart, knowing the CO_2 in the flue gas, and the H in the combustible, the % excess of air and the weight of air per lb. of combustible are ascertained.

C. *Harold Berry* states that for coal containing 70% carbon, 5% hydrogen, 7% oxygen, 1% nitrogen, burned completely with 10% excess air, the % SO_2 in the flue gas will equal the % sulphur in the coal, multiplied by .086, or a maximum of say 0.43% SO_2 from coal with 5% sulphur. Since some of the sulphur passes out unburned with the clinkers, and as some of the SO_2 will dissolve in the water of the Orsat, the amount of SO_2 reported as part of the CO_2 would normally be considerably less than indicated here. Of course a low concentration of this gas, especially in the presence of water, attacks metals with which it comes in contact. When figuring the weight of dry flue gas, the sulphur may be allowed for by adding to the factor "lb. carbon burned per lb fuel" ⅜ of the sulphur burned per lb. fuel. With a coal of 70% carbon and no sulphur, the factor is 0.70; while for 70% carbon and 5% sulphur, the factor becomes 0.7188, a difference of about 2.7%, while for fuels containing only 1 or 2% of sulphur, the correction will be less than 1% and may well be neglected.

C   HEAT CONTENT OF
        FLUE GASES
                    —*Feuerungstechnik.*
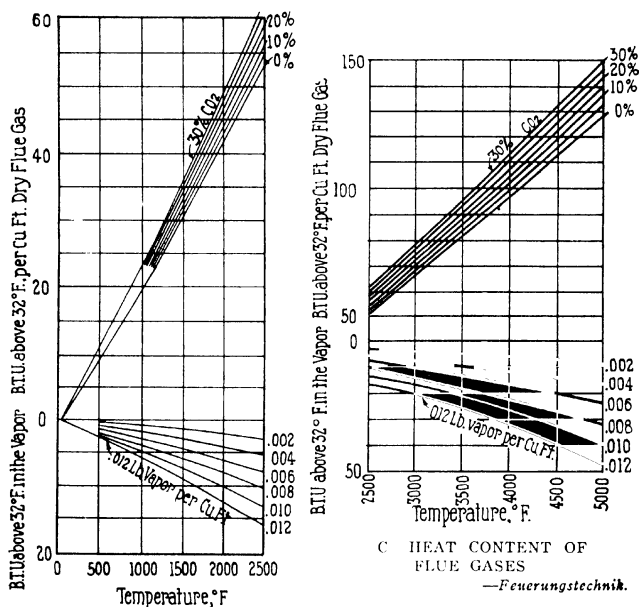
Carl *Schwarz* gives in Fig. C charts for the heat content of flue gases containing various quantities of CO_2 and water vapor, at different temperatures, all volumes expressed at atmospheric pressure and 59° F.

	Coal	Coal	Coal	Coal	Coal	Oil
Carbon	87.6	62.6	62.6	61.8	60.6	86.5
Hydrogen	3.4	3.4	3.4	4.4	5.4	13.0
Moisture	3.0	5.0	10.0	10.0	10.0	0.0
Oxygen	1.0	6.0	6.0	6.0	6.0	0.5
N₂ S₂ Ash	5.0	23.0	18.0	18.0	18.0	
Total	100.	100.	100.	100.	100.	100.
Max. CO₂	19.05	16.82	18.82	18.17	17.55	15.23

D F DEWPOINT TEMPERA-
TURES FOR COMBUSTION
PRODUCTS FIVE FUELS
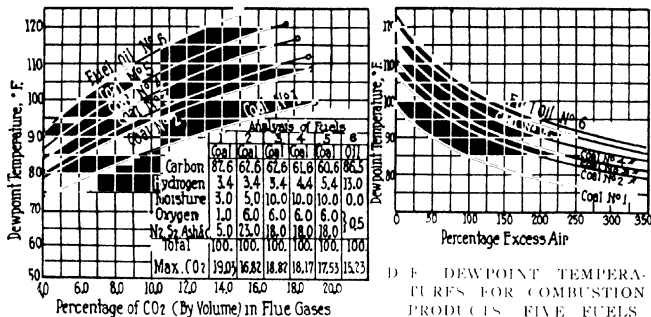
J. N. Waite has calculated the dewpoint temperatures given in Figs D and E for the vapor-gas mixtures resulting from the complete combustion of typical coals and oil, as a function of the excess air used in the combustion, or, more readily ascertained, the CO_2 percentage Dewpoint temperature is defined as the temperature at which water vapor begins to be deposited as liquid water, the statement often made that this occurs at 212° F. being manifestly incorrect Comparison of curves 2 and 3 shows that increase of moisture content of the fuel increases the vapor content of the gases and hence raises the dewpoint temperature, Nos 3, 4 and 5 show the effect of hydrogen in the coal in raising it; while fuel oil, with no appreciable moisture content but high hydrogen, gives gas of the highest dewpoint temperature The charts assume the air for combustion to be at 60° F., 30 in barometer and 100% humidity, but 75% humidity in the air supply reduces the resulting dewpoint temperature by only 2° F. If the final exit gas temperature is reduced to the *initial temperature* of the air before combustion, the moisture taken in as vapor will pass out as such, but practically all the moisture from the combustion of hydrogen and the moisture in the coal will be condensed and give up both sensible and latent heat If the final gas temperature is between the initial tem-

F. G. EFFECT OF EXIT TEMPERATURE ON EFFICIENCY TWO COALS
                                        —*Elec. Review.*
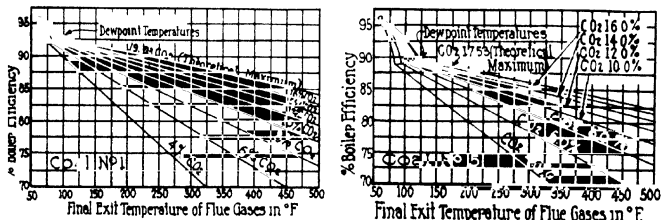
perature and the dewpoint temperature, part of the latent heat of vapor from hydrogen and from moisture in coal will be recovered; if above the dewpoint temperature, none of the latent heat will be recovered.

A curve for boiler efficiency as a function of exit gas temperature, for a given fuel and CO_2, has a kink at the dewpoint temperature, owing to the commencement of the recovery of the latent heat of the water vapor. For a given temperature below dewpoint, the volume of the gases can be calculated at the temperature, and as this is also the volume of the vapor carried by them if fully saturated, division by the specific volume of vapor of that temperature, gives the weight of vapor present in the gases. This, minus the vapor brought in with the air, gives the vapor resulting from combustion of hydrogen and from moisture in coal and remaining as vapor, and the latent and sensible heat carried away in it can be calculated, as can also the sensible heat in the vapor brought in with air, and in the other products of combustion. F and G show calculated boiler efficiencies for two of the coals investigated, assuming radiation and unburned fuel loss to be 4%.

W. Trinks gives a description of the *Ostwald-Seufert* graphic method for determining the excess air from the CO_2 and O_2 in flue gas. It requires the preparation of a diagram based on the ultimate analysis of the fuel, derived as follows for *liquid* and solid fuels.

For *complete combustion* without formation of CO.

$$\% \; CO_2 \text{ in flue gas, by vol} = k_c = \frac{3000c_o}{30c_o + O_c[(476/n) - 1]}$$

$$\% \; O_2 \text{ in flue gas, by vol} = q_c = \frac{100 \; O_c[(1/n) - 1]}{30c_o + O_c[(476/n) - 1]}$$

wherein $c_o = fraction$ of total carbon in fuel, by wt.

$O_c = theo.$ cu. ft. O_2 per lb. fuel, for complete combustion
$\quad = 30c_o + 89h_o$

$h_o =$ fraction of hydrogen in fuel, by wt

$n =$ ratio of theo. air volume to actual air vol

For *incomplete combustion*, no CO_2, but complete combustion of hydrogen:

$$\% \; CO \text{ in flue gas, by vol} = p_1 = \frac{3000c_o}{30c_o + (4.76/n)O_c - O_1}$$

$$\% \; O_2 \text{ in flue gas, by vol.} = q_1 = \frac{100 [(1/n)O_c - O_1]}{30c_o + (4.76/n)O_c - O_1}$$

$O_1 = theo.$ cu. ft. O_2 per lb. fuel, for incomplete combustion
$\quad = 15c_o + 89h_o$

Values of O_2 are laid off to the right, and of CO_2 up, from the point *A*, Fig. 1. k_c and q_c are calculated for $n = 0$, 0.1, etc., up to 1.6; each point representing a pair of values should lie on the straight perfect-combustion line connecting *B* (which is q_c for $n = 0$) with *C* (which is k_c for $n = 1.0$). (For very rough work only *B* and *C* need be determined, and *BC* can be divided decimally.) For n greater than 1.0, values of q_c are negative, and the points lie on the line extended beyond *C*, being only used for construction purposes. Values of q_1 for the same values of *n* are laid off on the line *AB*, and corresponding points (same *n*) on *AB* and

3. STACK GAS FROM COMBUSTION OF GIVEN PRODUCER GAS—

Blast Furnace & Steel Plant

BC are connected by constant air-ratio lines. From D, the point on AB where $n = 1$, a line DE is drawn perpendicular to BC, the value of p_1 is calculated at $D(n = 1)$, DE is subdivided accordingly, and constant CO lines drawn parallel to BC. The figures near the values of n show the corresponding % excess of air. All possible stack-gas analyses are represented by points within the triangle ABC, except gases containing hydrogen or soot, as from sheet-heating furnaces using bituminous coal. Data such as the following can be taken from Fig. 1, prepared for a coal of the analysis indicated:

Chart for Stack Gas Analysis
Calculated for Coal.

By weight:
Total Carbon —— 76.25 %
Oxygen —————— 6.53
Hydrogen ———— 4.95

Percent CO₂ (by volume)

Percent O₂ (by volume)
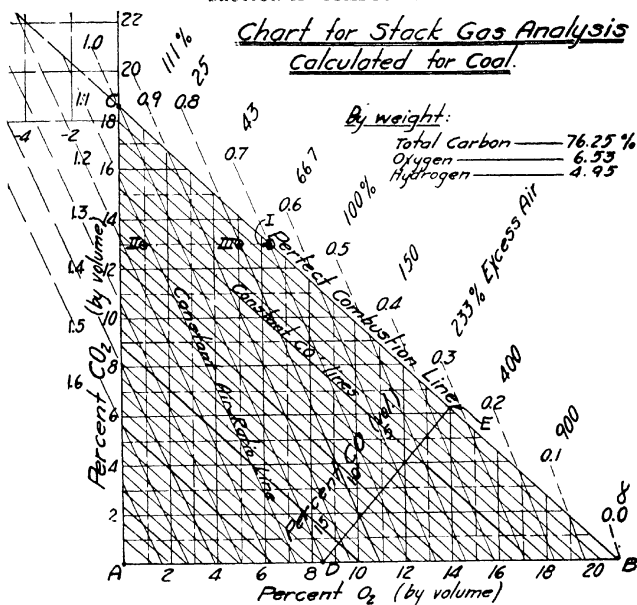
1. STACK GAS FROM COMBUSTION OF GIVEN COAL—
   Blast Furnace & Steel Plant

No.	CO₂ from stack-gas analysis, %	O₂ from stack-gas analysis, %	CO from chart, %	n from chart, %	1/n	
I.	13.0	6.3	0.0	0.70	1.43 = 43%	excess air
II.	13.0	1 0	7.2	1.125	0 89 = 11%	deficiency of air
III.	13.0	5.0	1.8	0.80	1 25 = 25%	excess air

In the third case, in spite of excess air, combustion is incomplete, caused possibly by imperfect mixture of air with the gases rising from the coal, or by chilling of the gases. Fig. 2 is a typical chart for combustion of by-product tar.

For *complete* combustion of *gases*, without *formation* of CO,

$$\% \ CO_2 \text{ in flue gas, by vol.} = k_c = \frac{100A}{A + N_o + [(4.76/n) - 1]O_c}$$

$$\% \ O_2 \text{ in flue gas, by vol.} = q_c = \frac{100O_c [(1/n) - 1]}{A + N_o + [(4.76/n) - 1]O_c}$$

Composition by volume: Coke Oven Gas

Hydrogen Sulphide	6 %
Hydrogen	15.4
Nitrogen	1.9
Carbon Monoxide	32.3
Methane (CH₄)	6
Oxygen	.5
Carbon Dioxide	2.1
Ethylene (C₂H₄)	47.6
	100.0 %

Composition by volume: Natural Gas

Hydrogen	3.1 %
Nitrogen	4.5
Carbon Monoxide	2.9
Methane (CH₄)	78.5
Oxygen	1.4
Carbon Dioxide	.3
Ethane (C₂H₆)	9.3
	100.0 %

Composition by weight: By-product Tar

Carbon	89.59 %
Hydrogen	6.21
Nitrogen	1.2
Sulphur	.77
Oxygen	3.21
Ash	1.0
	100.00 %

Water = 3.2 %

FIGS. 2, 4, 5. STACK GASES FROM COMBUSTION OF GIVEN FUELS—*Blast Furnace & Steel Plant*
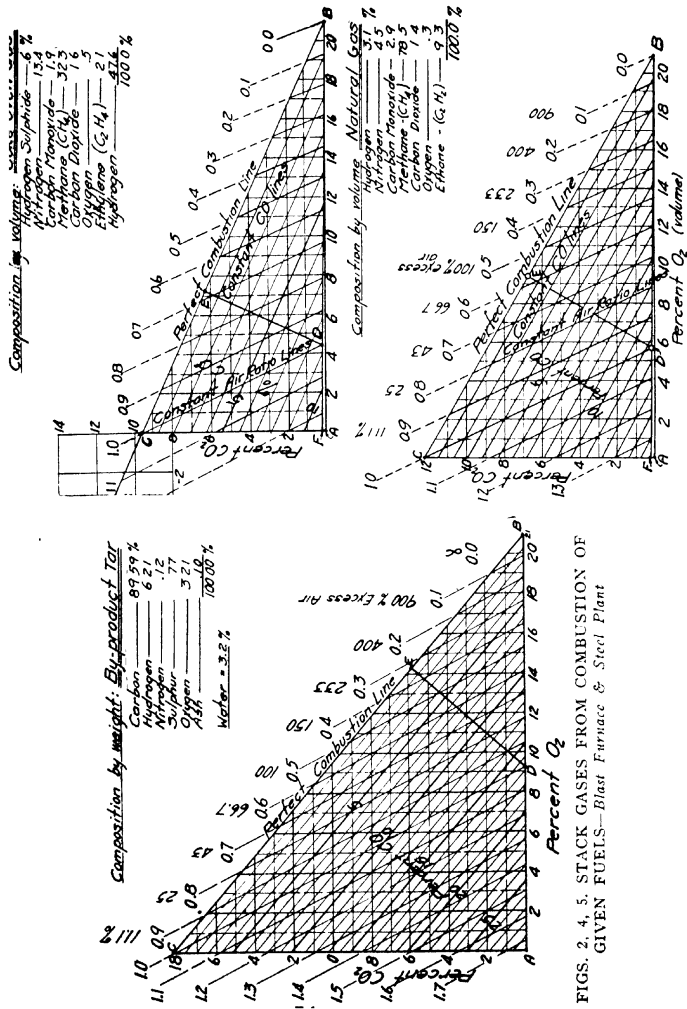
For *incomplete* combustion of *gases,* without *formation* of CO_2, but with complete combustion of hydrogen,

$$\% \ CO_2 \text{ in flue gas, by vol} = k_1 = \frac{100k_0}{k_0 + B + N_0 + (476/n)O_c - O_1}$$

$$\% \ CO \text{ in flue gas, by vol} = p_1 = \frac{100B}{k_0 + B + N_0 + (476/n)O_c - O_1}$$

$$\% \ O_2 \text{ in flue gas, by vol} = q_1 = \frac{100\,[(1/n)O_c - O_1]}{k_0 + B + N_0 + (476/n)O_c - O_1}$$

In the above five formulas,

$A = p_0 + v_0 + k_0 + 2r_0 + 2s_0$

$B = p_0 + v_0 + 2r_0 + 2s_0$

$O_c = $ theo cu. ft O_2 per cu ft fuel gas, complete combustion
$\quad = 0.5h_0 + 0.5p_0 + 2v_0 + 3r_0 + 2.5s_0 \quad q_0$

$O_1 = $ theo cu ft O_2 per cu. ft. fuel gas, incomplete combustion
$\quad = p_0 + v_0 + 2r_0 + 2s_0$

$n = $ ratio of theo air vol. to actual air vol

$h_0 = H_2, p_0 = CO, N_0 = $ nitrogen, $\quad v_0 = CH_4, k_0 = CO_2, q_0 = O_2, r_0 = C_2H_4,$
$s_0 = C_2H_2$, these representing *fractions* of various constituents, in the gas burned, expressed by volume.

Values of k_c and q_c are calculated for n from 0 to 1.6, and laid off on the line CB, as in Fig 3; values of k_1 and q_1 are laid off on the line BF (with many gases, BF will be close to AB) $\quad p_1 = CO$ in flue gas, is calculated for $n = 1$, point D, the line DE, drawn from D perpendicular to BC, is divided accordingly, and the constant-CO lines drawn parallel to BC. Constant air-ratio lines are drawn between points of equal n on lines BC and BF. These lines are straight, but in general will not be exactly parallel. The field in the triangle BCF includes all possible stack analyses from burning the producer gas indicated, provided all hydrogen has been burned. Figs. 4 and 5 were constructed by *Trinks* for typical coke-oven gas and natural gas.

Fig. A, pages 286 and 287, by *E C M Stahl*, is used in daily operation to determine the heat loss in dry flue gas from the complete gas analysis for CO_2, CO, O_2 and N_2. The method of use will be apparent from the arrowed dotted lines

The effects of excess air are graphically shown in Fig B, redrawn from *M. Gensch.* An average high-grade and an average low-grade coal were used; most commercial coals lie between the limits represented. The volume of gases goes up rapidly with excess air and may overload the chimney and draft equipment. With admission of excess air the theoretical combustion temperature drops rapidly. The flue temperature relations shown by *Gensch* should be contrasted with results obtained by the *Bureau of Mines* (see page 196). The *Bureau* states that combustion chamber temperature and flue gas temperature rise and fall together, although the results do not show this conclusively.
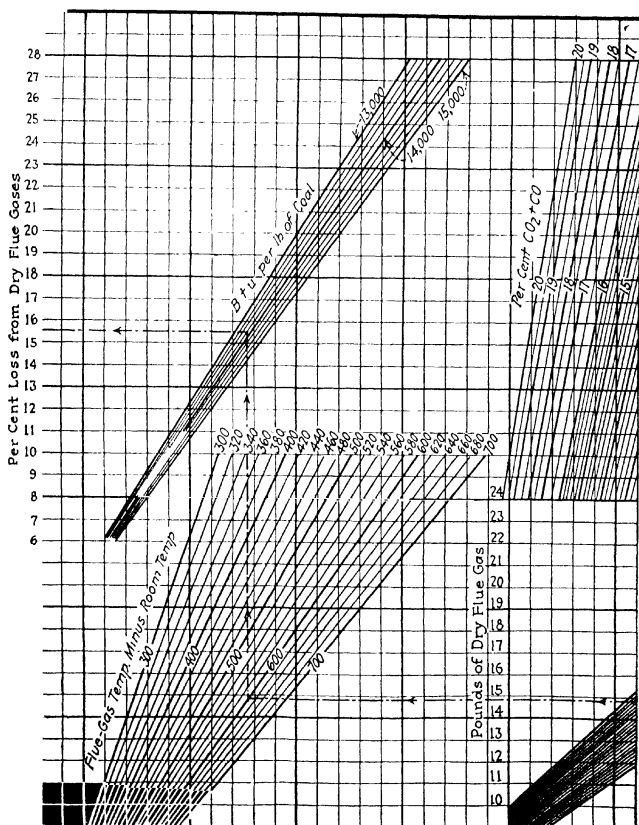
From analyses of the furnace and flue gases the *Bureau of Mines* has computed the following figures showing the average weight of gases per lb of carbon at different points in the gas passage:

Top of fuel bed............................... 8.4 lb.
Rear of combustion chamber.................. 17.2 lb.
Base of stack................................ 23.2 lb
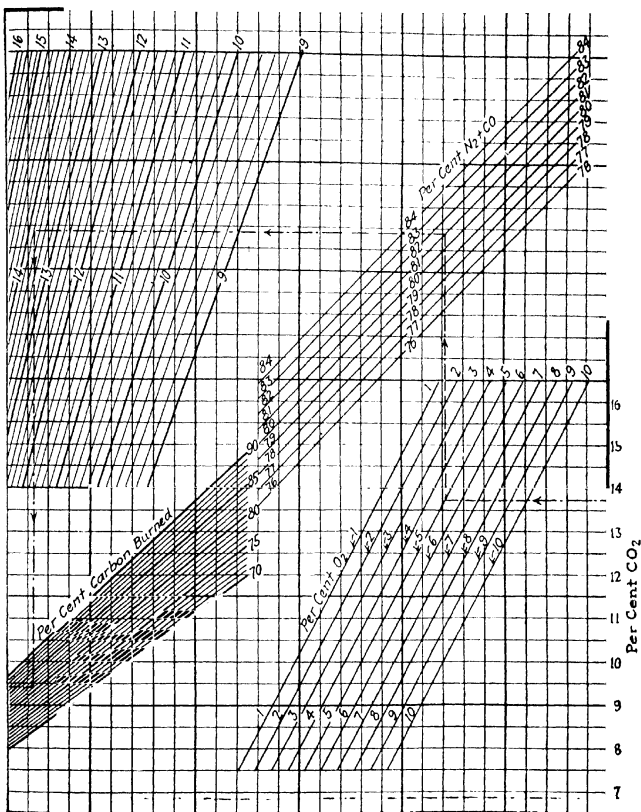
A   HEAT LOSS IN DRY FLUE GASES FROM COMPLETE FLUE GAS
ANALYSIS—*Power*

The *Bureau of Mines* points out that the leakage of air into a boiler
setting is significant only when compared with the air entering the furnace
through the grate or firing door. The same difference between the gas
pressures inside the setting and the outside atmosphere causes the same
weight of air to leak into a given setting. If the coal burns freely, and no
clinker is formed, the air finds little resistance in flowing through the

B   EFFECT OF EXCESS AIR ON THE MAXI-
    MUM ATTAINABLE TEMPERATURES AND
    EFFICIENCIES

	Analysis	Carbon	Hydrogen	Sulphur	Oxygen	Ash	Moisture	Heating value (dry coal)
Coal No 1 (as fired)		83	4	1	4	6	2	14,230 BTU
Coal No 2 (as fired)		51	4.5	2.5	19	9	14	10,000 BTU
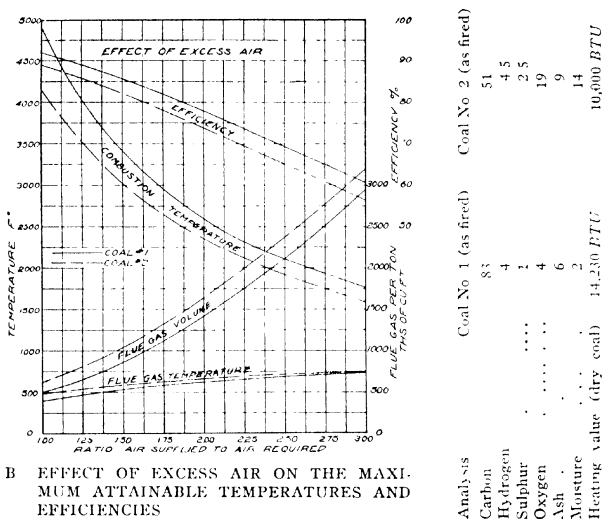
The two coals are the approximate limits of commercial coals. Volume of flu gases is in thousands cu ft per ton at the flue-gas temperature and atmospheric pres sure and shows how the draft fan would be loaded.

grate and fuel bed, and a large quantity of fuel is consumed. A larg quantity of air is also required through the firing door. In such a case th leakage of air through the setting would be a small part of the total ai used. In another case the coal may cake badly, and the whole fuel be may become fused. In addition, the fuel bed may be very thick. In thi case a smaller quantity of air would pass through the fuel bed for th given pressure difference, and the leakage through the setting would be much larger part of the total air used.

A good way to detect air leakage through holes in the fuel bed is t provide a double differential draft gage on the boiler front. As the fue resistance decreases, the draft through the fuel bed drops as compare with the draft through the boiler   The fireman is informed as to the fir conditions without opening the doors. Air leakage through the fuel be may be more serious than air leakage through the setting   The fires ma be too thin on the grates, and the fireman may not be careful to distribut the coal evenly over the grates

The importance of providing for the admission of the proper amoun of air above the fuel bed—secondary air—is shown by the table ou page 163. It makes no difference how the air gets in, whether throug special openings or through doors and cracks, except that it is essentia that it be properly distributed and that the temperature conditions ar right for burning gases.

A. *Kristian Bak* describes investigations made on the Detroit Edison W-type Stirling boiler illustrated on page 543 to determine the effects of varying amounts of CO_2 and CO on total stack loss. The data were calculated from temperatures and gas analyses only, a steam-flow meter being used merely as a check on the approximate rating carried on the boiler. The stack temperature and *total* stack loss (dry-gas loss, water vapor loss and combustible gas loss) are shown in Fig 1 as a function of the CO_2 content. It was impossible to carry 172% rating with less than 12% CO_2, and the minimum stack loss was found to be at or above 17% CO_2, indicating that for this particular boiler the highest possible CO_2 was the best, even though at 16.8% CO_2, 0.35% CO was found. Due to increased volume of air the power input to the fan was four times as great at 10% CO_2 as at 16%. It was found, however, that the best *plant* efficiency was at 16 2% CO_2, as shown in Fig 2, the CO at this point being 0 2%. Lowering the boiler losses by higher CO_2 also lowers the temperature and total heat of the steam leaving the boiler, which affects turbine operation, the increase in steam rate being 1% per 11° drop in temperature. Fig. 2 is 4 or 5 points too high, the only auxiliaries considered being the forced-draft fan, but the shape is approximately correct. Fig. 3, page 291, shows stack-gas loss for given percentages of CO_2 and CO, taking into consideration the variation in gas temperature, showing that 15% CO_2 with 0 25% CO is more economical than 14% CO_2 and no CO, and equal to 15.5% CO_2 with 0 5% CO.
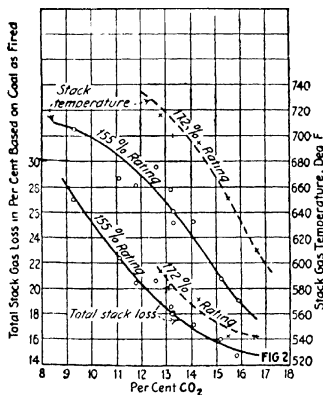
1. EFFECT OF CO_2 ON TOTAL
STACK LOSS
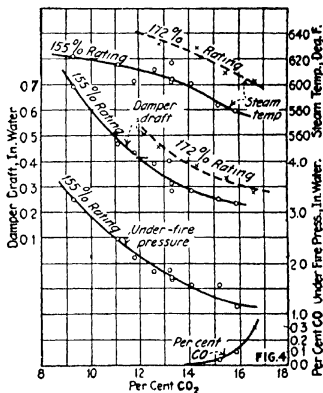
2. EFFECT OF CO_2 ON PLANT
EFFICIENCY

—*Power.*

CARE OF SETTING TO REDUCE EXCESS AIR

The following suggestions by *Hays* are helpful in making a setting tight:

Do not assume that any crack is not conducting air to the heating surface. A crevice between an eye-beam or a stay and the brick work may lead to some hidden avenue that will carry cold air where it will do a lot of damage. Don't forget the brick on top of the boiler. Don't make a casual inspection for cracks.

Use a candle on the boiler setting, also on the boiler headers. Inspect for air leakage at clean-out doors, blow-off pipes, etc.

Another method of detecting leaks is to keep the boiler walls whitewashed, so that inflow of air will be shown by the accumulation of coal dust around the cracks.

The loss due to air leaks in a furnace and boiler setting is 10% of the heat generated in the furnace, as a conservative estimate for the average power plant.

D. G. Wallace suggests that a boiler which has been repaired or inspected should be examined for air leaks before firing up. With the grate covered with the same depth of coal as when fired, and the damper opened to give the same draft reading as under operating conditions, a man with a torch inside in the setting can easily locate any points where air will leak in.

Uehling suggests that the air leaks can be located by firing up strongly, opening the damper wide and suddenly closing it tight. Smoke will issue from all considerable cracks.

Air leaks in a return tubular boiler may be caused as follows: Expansion of the boiler may push back the arch, leaving an opening of ½ in width. The arch may be broken; there may be excessive clearance around the blow-off pipe. There may be loose doors and door frames.

Morgan B. Smith suggests the following repairs for a setting which has very poor joints, in which the bricks are porous and where the door frames are loose. First remove thoroughly the old, worn-out lime mortar in the joints of the brick work to a depth of fully one inch and clean the bricks with wire brushes. Point up the bricks with mortar of cement and fire-clay. Add enough ammonia to this mortar so that it has a fairly strong odor. This tends to retard the setting and makes the mixture more resistant to temperature changes. Joints should be made flush with the surface of the brick and allowed to set for two days. The whole setting, including the iron work, should be painted with a heavy, slow-drying asphaltum-base paint, giving a flexible coating not easily cracked or peeled off. Three coats of paint should be applied, and the total work on the setting should take about 10 days. This paint is gummy and heals when scratched. There are several such on the market. In one installation before such treatment the % of CO_2 in the gas at the top of the last pass was 8.5%, while after treatment it was 13%, the same as in the first pass.

Hays recommends not to plaster the cracks in a setting, but to caulk them, as plaster shrinks and falls out. Make a very thin mixture of fire-clay and cotton waste, first pulling the waste apart so that the fibers of it will be covered with the clay. Use a sharpened piece of wood as a caulking tool. Drive the caulking material in tight. This can be done while the boiler is in operation. There are cements on the market for this purpose.
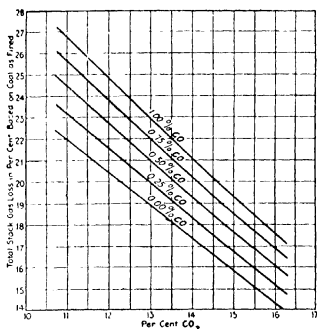
3 EFFECT OF CO_2 AND CO ON TOTAL STACK LOSS—*Power*
(See page 289)
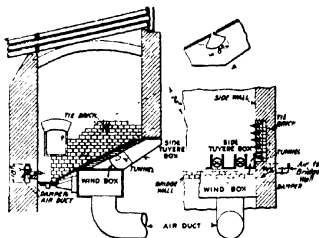
BERNITZ SYSTEM, TAYLOR STOKER
—*Power.*

In the *Bernitz* patented system of ventilating side walls as used to prevent the adhesion of clinker, air is supplied under pressure through chambers in the wall. Several courses of headers without fire-clay between the side joints serve to admit sufficient air to keep the walls cool.

Old magnesia pipe covering made into paste with water is satisfactory for plugging cracks in the setting. The cracks can also be stopped with asbestos rope or cement Lime or cement mortar lacks elasticity, and often falls out after drying.

The effect of an elastic coating on a brick setting in reducing air infiltration is shown by the adjoining chart, due to the *Vulcan-Lastite Co* The average CO_2 was increased from 9 6 to 12.7%, representing a fuel saving of 4 2%.
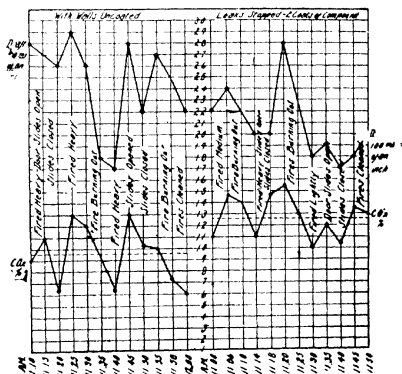
EFFECT OF STOPPING AIR LEAKS
—*Elec. Review.*

SOOT

As found in steam boilers, "soot" is little like lampblack, and often it is not even black. Even if ideal conditions of combustion are continuously maintained, so that no amorphous carbon is formed, the tube surfaces will rapidly become covered with an insulating coating, formed largely of ash.

The deposit may range in color from gray, green, red and brown to white. In tests made by the *U. S. Bureau of Mines* at the St. Louis Exposition, the weight of earthy matter in the refuse from a test was usually 15 to 20% short of the amount indicated by a chemical analysis of the coal. This difference is accounted for by the quantity of refuse and ash carried by the current of gas into the combustion chamber and up the stack.

This deposit often fuses at low temperatures, and the effect of the coating is cumulative, first insulating the tubes and causing the chimney gas temperatures to rise. Then due to the higher temperature, it fuses and forms a more impenetrable coating, with consequent still higher gas temperature. Fused soot has even been known to bridge over between the tubes, thus choking the draft and reducing the capacity. Soot is formed in all boiler installations, no matter what the fuel, whether it be hard or soft coal, oil, blast-furnace gas, or refuse.

The higher the draft intensity, the greater will be the amount of soot. The combustible particles of the soot are due to incomplete combustion; the draft may even carry small particles of coal through the combustion chamber unignited. If the combustion chamber is small and the temperature low, the hydrocarbons will not burn completely therein, and small particles of carbon will pass on with the gases.

The carbon portion of soot is generally ascribed to the decomposition of hydrocarbons, which occurs rapidly after their distillation. It may also be due to the dissociation of CO at relatively low temperatures. This is a phenomenon frequently observed in metallurgical work, and would account for many cases of heavy soot formation with no CO in the issuing gas.

The rate of soot accumulation depends on the coal. Instances have been known where 1 in. accumulated on top of tubes in an 8-hr. run. Accumulations of dust in flues may be sufficient to cut down the draft and thus interfere with the operation of the boilers.

All boilers should have the soot blown off the tubes every day. Fire-tube boilers should have the tubes scraped twice a month, to remove tarry soot. If a furnace never smokes, there may be little carbon soot on the tubes, but there can be a great deal of fine ash, even from anthracite.

EFFECT OF SOOT BLOWING ON FLUE TEMPERATURE IN A HORIZONTAL
VERTICALLY BAFFLED BOILER

It is claimed that mechanical blowers will remove soot with the same steam consumption as the hand lance or hose, at one-third the cost in time and labor, and three times as efficiently, because all surfaces are reached. Soot is not piled up on the far tubes, and less cold air is admitted. The hand lance takes 20 to 30 min. for the operation, on a medium-sized boiler. The above chart from *Power* is typical of the results secured by the removal of soot from the tubes. It is estimated that every 20° F. drop in the uptake temperature saves 1% of fuel. The cost of mechanical blowing equipment is 5 to 10% that of the boiler, the upkeep is small, and the labor cost is decidedly less than for hand blowing.

Fig. A, from *Power Plant Engineering*, serves to bring out the advantages of frequent blowing of soot from boiler tubes, although it is probable that the resistance to heat flow does not increase in a linear relation to time, as indicated by the chart, but follows a curved line that falls off from the straight line as the time increases A similar study could be made of the benefit of scale removal
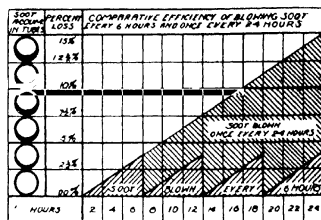
A EFFECT OF INTERVAL BE-TWEEN SOOT BLOWINGS

The *Vulcan Soot Blower Co* says. "Figures from one of the largest electric light plants in the country, regarding a new and perfectly clean 600-HP. horizontal water tube boiler operated at 150% of rating, show that the uptake temperatures for the first day were an average of 550° F., while on the fifth day the average uptake temperatures had risen to 650° F. The increase of 100° in flue-gas temperature in four days represents an increase in coal consumption of approximately 5%. These boilers were not cleaned, and the figures given are a good indication of the rapidity with which soot insulates the tube surface and cuts down economy, as the time a boiler has been in service increases. Tests made by *A. W. Conklin*, Combustion Engineer, showed the following temperatures:

	Near Bottom 1st Pass	Top 1st Pass	Bottom 2d Pass	Top 3d Pass
Hand blown	1697	954	727	618
Cleaned by Steam Blower	1691	934	649	527

Gas temperatures were read at the points indicated, in a horizontal water tube boiler In the first case the tube surface was blown thoroughly by a steam lance and the average temperature of the flue gas was 618°. In the second case, with the steam blower in use, the exit temperature was 527°, the difference in temperatures representing between 4 and 5% gain.

"The following figures relate to flue-gas temperatures in Stirling boilers in two plants, one, a large industrial plant; the other, a hotel in Chicago In the first the decrease in average flue-gas temperature was 81° with a slightly higher furnace temperature In the second the average temperature of the chimney gases fell 164°, the furnace temperatures being practically identical. The increases in heat absorption in favor of the mechanically cleaned boilers were 8 6% and 12.46% respectively.

"On a test recently made on a 300-HP B. & W. boiler in a large gas works, to determine the efficiency of mechanical blowers, it was found that by using the blower every six hours, instead of once in every 24, as had been the practice with the hand jet, the average stack temperatures were reduced 110°, the boiler efficiency increased about 4%, and there was a saving of six hours' labor of one man each 24 hours operation."

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According to *Kreisinger, Augustine* and *Katz*, of the *Bureau of Mines,* smoke formation is not due to chilling of combustible furnace gases by premature contact with boiler tubes, but to decomposition of hydrocarbons at high temperatures. The volatile leaves the fuel bed in the form of heavy hydrocarbons, 12% as tarry matter in the case of bituminous fuels. In the absence of oxygen, and at high temperatures, a series of reactions takes place by which these are decomposed to lighter hydrocarbons, and at each step solid carbon or soot is separated, all in a fraction of a second. To correct this, the issuing gases should be met by a supply of secondary air.

Fig. A, adapted from *Paul Fuchs,* represents the density of smoke as a function of the hydrogen content of the coal. The Ringelman system of stating smoke density is explained in the next section.

The table below shows the relations between smoke, *CO* and temperature obtained at the *St. Louis Testing Plant.* It shows that *CO* and dense black smoke increase together, that the combustion chamber temperature increases with *CO*, as suggested above, and that high smoke values and high unaccounted-for losses go together.
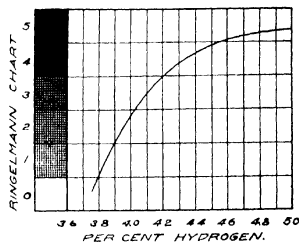
A   VARIATION OF SMOKE DENS-
ITY WITH HYDROGEN CON-
TENT OF COAL

SMOKE, *CO* AND TEMPERATURE

				% Black Smoke			
	0	0-10	10 20	20 30	30 40	40 50	50 60
No. of tests. . . .	37	18	56	51	36	17	4
Aver. % smoke . .	0	7 1	15 5	24 7	34 7	43.1	52.9
Aver. % *CO* in gases	05	11	.11	.14	.21	.33	.35
Aver % unaccounted for in heat balance. . . .	9 14	10 60	9 46	10 93	11 41	13 41	13 34
Aver. combustion chamber temperature, ° F	2180	2215	2357	2415	2450	2465	2617

SMOKE DETERMINATIONS

Self-interest tends to prevent the continuous production of dense smoke, but the requirements of the public for relief from the smoke nuisance call for its curtailment further than mere money saving would justify. The fixing of a standard to determine the amount of smoke which constitutes a nuisance, or the number of minutes per day that emergency conditions may be held to excuse the production of smoke, is, of course, a difficult matter. *J. S. Owens* suggests that the true standard of comparison should not be the degree of opacity, which is influenced by the size of the column issuing, but the actual density of the smoke, or the amount of soot emitted per cubic foot. The large plant which is pro-

ducing power in quantities, and perhaps rendering unnecessary a number of small plants, should be permitted to produce a larger total quantity of smoke than its smaller neighbors. For the enforcement of such standards he suggests a telescope, into the field of which can be rotated a number of half-lenses of varying thicknesses of dark glass, corresponding to a range of chimney diameters, by which it can be determined if the permitted opacity for the given diameter has been exceeded. Ordinances directed against the smoke nuisance without giving any standard are, of course, of little effect, except insofar as they provide for co-operation between inspectors and owners, and for the approval of designs for new plants. Many cities permit the production of dense smoke for not over six minutes in an hour, or in the early morning, and some have adopted a regular classification according to the size of stack, giving permissible limits of smoke of different opacities.

The most generally used basis of qualitative smoke measurement is the Ringelmann Chart. This consists of four large charts ruled with vertical and horizontal lines forming squares. No. 1 is ruled with lines 1 mm. thick and spaces 9 mm. wide. No. 2 is ruled with 2.3 mm. lines and spaces 7.7 mm. wide. No. 3 is ruled with lines 3.7 mm. and spaces 6.3 mm. No. 4 is ruled with 5.5 mm. lines, and spaces 4 5 mm. The cards are placed 50 ft. from the observer, in line with the chimney, together with a white card and one that is solid black. The observer glances rapidly from the chimney to the cards, and judges which one corresponds with the color and density of the smoke. Ringelmann readings are usually taken at ½ to 1 min. intervals during an hour or more. The readings are plotted in a log. This plot gives a good general idea of the manner and regularity of smoke emission, but is very unsatisfactory for comparing stacks.

The proposed *A S.M.E. Test Code* states that readings should be recorded according to the following scale of values:

Card	Smoke Density	Description
No. 5 (black)	100%	Dense black
No. 4	80%	Medium black
No. 3	60%	Dense gray
No. 2	40%	Medium gray
No. 1	20%	Light gray
Between No. 0 and 1......	1%	Trace
No. 0 (white)	0%	Clear

It is to be noted that the above rules apply as stated to smoke in which the particles are black. In some cases, however, the smoke may be inherently of some other color, as, for instance, some shade of brown.

RINGELMANN SCALE FOR GRADING SMOKE DENSITY
—*A.S.M.E.*
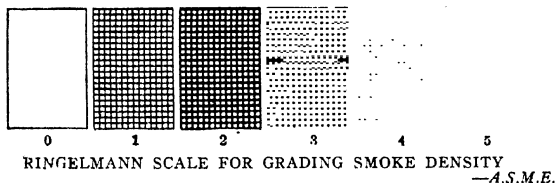
For such cases the same charts and methods shall be used. The observer will now grade the smoke by number according to its density in terms of the base color other than black, whatever it is. For instance, if the color be brown, a smoke of 100% brown smoke shall be recorded as Card No. 5, etc.

The color and density of smoke depend somewhat on the character of the sky or other background, and on the air and weather conditions obtaining when the observation is made, and these should be given due consideration in making comparisons. Observations of this kind are also subject to personal errors and errors of judgment. Nevertheless these methods are useful especially when the results are plotted, according to the percentage scale determined on, so that a graphic representation of the changes can be shown. The observations should be considered as only roughly indicating the smoke conditions and are comparable only when made by the same observer.

Another method of plotting results, suggested by *E. G. Bailey*, is to find the total time during the day represented by each density, reduce it to minutes per hour, and add to it the number of minutes corresponding to each higher density. The totals are plotted against the Ringelmann chart numbers, and the curve represents the fraction of time during which each given degree of smoke density has been reached or exceeded.

Bailey remarks that Ringelmann chart No. 5 includes all smoke that is opaque. Twice as much carbon can be carried at one time as at another, and not affect the density reading.

Admiral R. T. Hall describes an electrical means of determining the density of smoke, used on the U. S. S. Conyngham. The basic principle is the sensitivity of the metal selenium to light as affecting the passage of electric current. A selenium disk connected to the ship lighting circuit was placed on one side of the stack opposite a light on the other. The intensity of the beam of light striking the disk, of course, varied with the density of the smoke. A milliammeter with a suitably graduated scale indicated the changes in current due to the changes in smoke density.
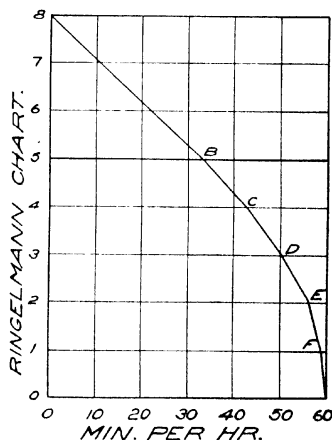
METHOD OF PLOTTING RINGEL-
MANN READINGS

—*A.S.M.E.*

SMOKE PREVENTION

The following measures will assist in the prevention of smoke:

1. The coal should be supplied in small quantities and at frequent intervals. The more nearly the feeding approaches a continuous and uniform supply the better.

2. The air supply should be slightly in excess of the theoretical requirements. An auxiliary supply at the front or rear of the furnace should burn the gases.

3. The temperature in the furnace should be sufficiently high to ignite the gas.

4. A fire-brick combustion chamber, designed to cause thorough mixing of the gases and air, should be provided, but there should be no firebrick arch over the grate.

The following table by the *Bureau of Mines* shows the result of tests to determine the best method of hand-firing high-volatile Illinois coals of nut size, using natural draft. The "ribbon" method consisted of firing alternately narrow strips the full length of the grate. This gave the highest efficiency and practically no smoke. The spreading method gave the most smoke and the lowest efficiency.

Method	Draft	Efficiency %	Black smoke %	Aver interval between firing, min.	Coal per firing, lb.	% rated Capac'y
Ribbon,	Natural ...	62 22%	5	2 3	50	106 7
Coking,	Natural... .	60.49%	15	7.4	140	95.
Alternate,	Natural. ..	59 87%	15 8	3.5	70	106.5
Spreading,	Natural ...	57.56%	32	9 3	170	92.7
Alternate,	Forced.. .	60 2%	14 9	3.4	85	131.6

Tests on lignite, peat and sub-bituminous coals which have a volatile content of 47 to 67% showed that they can be burned in hand-fired furnaces with a small amount of smoke.

Briquetting offers hand-fired plants a means of developing high capacity practically without smoke, and at good efficiency Briquettes gave an efficiency 1 to 3% greater, developed a higher capacity, and were consumed much more completely than the raw coal.

A well-designed and operated furnace will burn many coals without smoke up to a certain rate of combustion, that rate depending upon the coal. Above this rate, the efficiency will decrease, and smoke will result, owing to lack of furnace capacity to supply air and mix the gases.

It is possible to design and operate a boiler plant to burn a high volatile coal with practically no smoke except when a fresh fire is built.

The air admittance to the furnace is very important. Very little free oxygen passes through the fuel bed Additional air must be admitted through the fire door, through special openings in the fire door or in the dead plate, or through the bridge wall. A combination of all these may be used. The best method is that which gives the best mixing. Extra air admitted at firing and for a short period thereafter increases efficiency and reduces smoke. Devices for admitting air at the front of the furnace and at the bridge wall appear to be equally effective in reducing the

amount of smoke. Where air is admitted only through the fire door or through the dead plate, the mixing is due only to natural diffusion. Additional air should be admitted for several minutes after each firing, across the fire close to the fuel bed, through auxiliary dampers having an area of at least 4 sq. in. per sq. ft of grate area. If additional air is also admitted through the bridge wall, the gases are between two streams of oxygen.

Osborn Monnett states that while the admission of air, to be mixed with the volatile gases, is the natural method of insuring complete combustion, the small combustion space makes it practically impossible to secure this result with hand-fired Scotch marine boilers   With hand firing, as *Henry Kreisinger* remarks, the rate of distillation is too spasmodic for the air supply to be adjusted to it, especially on shipboard. The oxygen is consumed in burning the carbon in the lower layer of the fire, and sooty smoke is formed at the surface of the fuel bed because there is insufficient oxygen to burn the volatile   The underfeed stoker is the most practical solution of the problem with this type of boiler   The fuel is fed uniformly, the air can be adjusted to it, and there is abundant oxygen in the air supply at the point where distillation takes place   The same is true of pulverized coal, which can be mixed with air externally.

Mixing the gases by special fire-brick structures, such as deflector arches and wing walls, is satisfactory   The chief objection is the lack of durability   A large combustion space affords more chance for mixing.

Steam jets are sometimes used for assisting in the mixing of the gases and air   They are usually placed above the fire door   The best method is to admit air through small openings around the jet, which acts like an injector   The nozzles should be properly designed to give a high velocity with a small steam consumption   If allowed to run continuously a steam jet probably wastes more of the energy of the coal than it will save. If properly regulated, it will keep a stack clean and save coal. It is an expensive device, all things considered, and its only purpose is to mix the air and gases intimately.   It is probable that a part of the dissociated hydrogen from the steam goes up the stack unburned, so that the considerable heat required to break up the steam is lost   Another loss is the heat put into superheating the steam up to the stack temperature

Experiments by the *Bureau of Mines* show that to effect complete combustion the amount of space must be proportional to the product of the volatile content by the ratio of volatile carbon to available hydrogen. The latter figure, in three coals tested, was 2 16 for Pocahontas, 4 35 for Pittsburgh and 66 for Illinois coal   The first-named gives off light, easily-burned gases, while the Illinois coal gives off tars, which decompose into soot and lighter hydrocarbons, requiring large space for their combustion. Distillation of the gases at low temperatures has the advantage that it produces light hydrocarbons of the paraffin series, high in hydrogen, which are more stable when further heated, and which burn more easily, because hydrogen is oxidized far less quantity of oxygen than is carbon   After the volatile matter is distilled, air should be added and the mixture passed through a hot chamber   High temperatures and the absence of oxygen tend to cause even methane to deposit soot   During the first foot of travel from the fuel bed the tars or heavy hydrocarbons quickly break down into soot and lighter hydrocarbons   The heating sur-
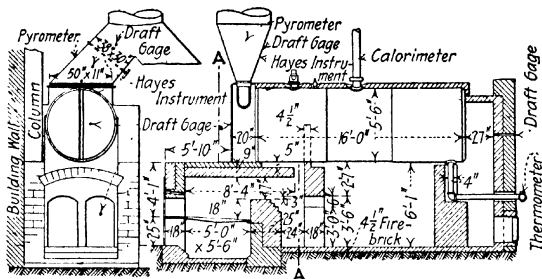
Section A-A

1. FULL EXTENSION, TWO-SPAN DEFLECTION ARCH SETTING
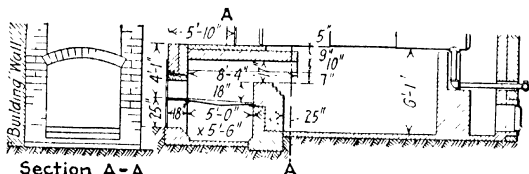
Section A-A

2. SAME AS 1, BUT WITH DEFLECTION ARCH REMOVED
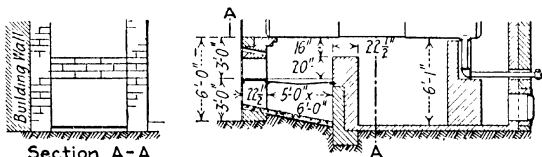
Section A-A

3. PLAIN OR COMMON SETTING
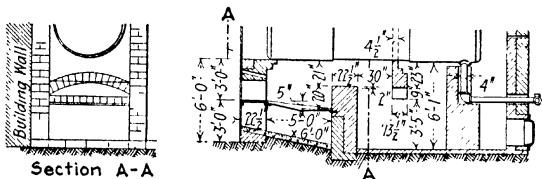
Section A-A

4. PLAIN SETTING WITH DEFLECTION ARCH

SETTINGS TESTED FOR EFFECT OF MIXING ARCHES

—Power.

Section A-A   A
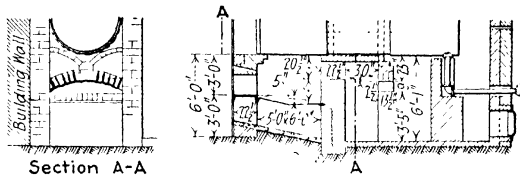
5   DOUBLE ARCH BRIDGE WALL FURNACE

faces are not the primary cause of soot, they merely cool the gases and prevent the soot from burning. In fact, soot requires for its combustion 12 molecules of oxygen to 1 of carbon, and is practically incombustible in a furnace atmosphere. Air supplied over the fuel bed should be admitted as near to its surface as possible and mixed with the hydrocarbons so that they will burn before soot is formed.

As *Jos Harrington* remarks, the gases are in the furnace only a few seconds. Every foot of flame travel must be made as effective as possible. Any delay in starting the combustion seriously affects the ability to complete it before the gases leave the furnace. A proper place to ignite the gases is the instant they leave the coal   A reflecting ignition arch will do this

The effect of **mixing arches** in a return-tubular boiler setting is shown by *S H Vail* on the five settings indicated in the sketches on p. 300, which showed the following results.

EFFECTS OF MIXING ARCHES ON FURNACE ECONOMY

Type of furnace Fig No.	1	2	3	4	5		
Carbon dioxide, %	8 90	9 40	9 20	9 10	8 60	11 48	12 70
Carbon monoxide, %	0	0	0	0	0	0	0 06
Oxygen, %	10 80	10 20	10 50	10 40	11 10	7 49	5.90
Nitrogen %	80 30	80 40	80 30	80 50	80 30	81 03	81 34
Temp of uptake gases, ° F	611	672	665	678	681	430	549
Temperature of steam, ° F	333	335	336	343	335	367	369
Diff between uptake and steam temp , ° F	278	337	329	335	346	63	180
Dry stack gases per lb coal as fired lb	15 65	14 98	15 81	15 23	15 55	11 35	12.00
Coal as fired, per sq ft grate per hr , lb.	22 63	24 62	24 70	24 80	26 60	22 70	35.70
Draft over fire in of water	0 116	0 113	0 226	0 226	0 245	0 090	0 220
Coal per sq ft of grate per hr per 0 01 in of draft. lb	1 95	2 18	1 09	1 10	1 08	2 52	1 62
Moisture in coal as fired, %	15 40	16 30	10 10	11 30	10 90	15 90	15 20
Combustible in coal as fired, %	73 50	73 32	76 77	73 89	75 02	70 75	70 72
Ash in coal as fired, %	11 10	10 38	13 13	14 81	14 08	13 35	14 08
BTU per lb. coal as fired	10,674	10 716	11 225	10 618	10 728	9 872	10,032
Combined boiler and furnace eff , %	50 20	57 50	53 90	55 10	56.50	72 67	72.55
Heat losses accounted for	28 80	29 11	28 40	30 49	32 30	16.27	23 08
Heat losses unaccounted for	21 00	13 39	17 70	14 41	11.20	11.06	4.37

The tests were all made upon the same boiler under conditions which made them comparable. The gas samples were taken at a point above the damper. The brick setting, which was five years old and cracked, permitted considerable air infiltration. Undoubtedly the CO_2 was between 2 and 4% higher in the combustion chamber at the end of the flame. The CO_2 figures are therefore only a relative indication of the conditions at the end of the flame.

In No. 1 test a deflection arch was used, while in No. 2 an open furnace was used. The unaccounted losses are 21% and 13.39% respectively. In the latter case the gases made only one right-angle turn between the fire and the rear end of the combustion chamber, as compared to three turns when the deflection arch was used. These results do not check apparently with the statement that turning the gases betters the mixture and reduces the unaccounted for losses. It may be explained, however, that during No. 1 test a thin fire was carried and holes were frequently burned through. Radiation from the brick roof and the side of the furnace caused a distillation of almost explosive violence when fresh coal was supplied. There were therefore alternate periods of excess air and of shortage of air during distillation. The CO_2 readings indicate that the excess air was not serious. The high unaccounted for losses may be due to bad sampling of gases, bad analysis, especially for CO, or incorrect flue-gas temperature determination. During No. 2 test the fires were carried a little thicker, and the fire-doors were left open a few inches for a few seconds to a minute or so after each firing. This admitted the air when most needed. The decrease in unaccounted for losses indicates that much of the volatile combustible had been oxidized.

In No. 3 series the unaccounted losses were 17.7%. In No. 4 series, the gases made two additional right-angle turns in passing from the fire to the rear of the boiler. This produced a better mixture, and the unaccounted for losses decreased. The accounted for losses in the stack and ash-pit were greater, but the decrease in the unaccounted for losses resulted in a net gain in efficiency of 1.2%.

Spreading fresh coal on the fire cools the furnace. The temperature above the fire may drop below the ignition point of some of the distillates, which may retard, without stopping, distillation. Particles of liquid oil will continue to be driven off from the coal. The heat in the furnace may not be sufficient to evaporate all of the oil and raise the resulting gas to an igniting temperature. The setting in Fig. 5 was developed to overcome these difficulties. The function of the brick-work in the double arch and the deflection arch is to cause the gases to dip and turn as steam does in passing through a separator. The oils are precipitated on the brick-work and held until gasified. The hot brick-work then ignites the gases.

Exposing the fire on the grate to the cooling influences of the boiler shell, as in Settings 3, 4 and 5, lowers the average furnace temperature below that obtained in a fire-brick enclosed furnace. The distillation is less rapid and more uniform, allowing more time for air to enter the furnace for burning the combustible gases.

The unaccounted for losses in No. 5 series were 3.2% less than in No. 4, and 6.5% less than in No. 3. The efficiency was better. This shows that double arches and deflection arches are a benefit, and do to some degree effect the purpose for which they are provided.

It may be thought that such variation in losses can occur only in a badly operated hand-fired plant, but to show that such losses will occur in the best plants, two extra columns have been added. These data are from two tests upon a 300 HP. vertically-baffled horizontal water-tube boiler, equipped with a chain-grate stoker burning Illinois screenings. The construction of the plant and the general plan and skill of operation were unusually high class.

Headroom Requirements for Smokeless Settings

Copyright by Osborn Monnett

(All dimensions in inches)

FURNACES:	Horizontal Return Tubular Boilers 54 60 66 72 (Shell to dead plate)	Water Tube Boilers Hor. Vert. Hor. Vert. Baff. Baff. Baff. Baff. 1-1½" 1-1½" 3¼" 3¼" Pitch Pitch Pitch Pitch (Front header to floor)	Continental or Scotch Marine
Hand-Fired:			
No. 6	32 34 34 36	72 * 78 *	**
No. 7	36 40 40 42	† † † †	**
No. 8	32 34 34 36	72 * 78 *	**
	(Shell to floor)		.
Down draft	60 60 60 60	72 * 78 *	*
McMillan.	52 54 60 60	72 * 78 *	**
Twin fire	58 60 62 64	72 * 78 *	*
Semi-ext. refuse burning	†† †† †† ††	84 * 90 *	*
Gravity Feed:			
Burke	48 48 50 54	60 * 66 *	Full extension
McMillan	48 48 50 54	60 * 66 *.	Full extension
Chain grate . . .	72 72 78 78	84 114 96 120	**
Front Feed:			
Moore	48 54 60 60	72 102 78 108	**
Roney	60 60 60 72	84 108 90 120	**
20th Cent .	54 60 66 72	84 108 90 120	**
Side Feed‡			
Detroit . .	66 72 78 84	90 * 96 *	Full extension
Model	66 72 78 84	90 * 96 *	Full extension
McKenzie . . .	66 70 70 70	90 * 96 *	Full extension
Murphy . . .	66 72 78 84	90 * 96 *	Full extension
Under Feed:	(Shell to dead plate)		
American	42 42 42 42	78 96 84 102	**
Jones	36 38 40 42	78 96 84 102	Min. diam. of furnace 36 in.
Taylor	** ** ** **	84 102 90 108	**
Westinghouse	** ** ** **	84 102 90 108	**

* Combinations not recommended as smokeless settings

** Combinations not ordinarily met with in practice.

† Not adapted to water-tube boilers.

†† Applied only to water-tube boilers. No. 8 better for H.R.T. boilers.

‡ Exceptionally wide settings will require more head room to take care of extra spring of arch.
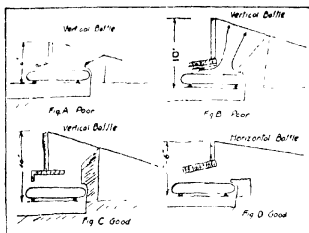
1. SOME CHARACTERISTICS OF CHAIN GRATE SETTINGS
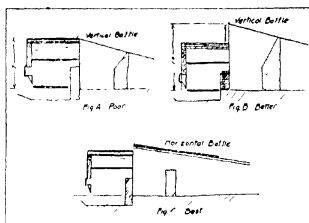
2 DOUBLE INCLINED STOKERS AND HORIZONTAL WATER-TUBE BOILERS
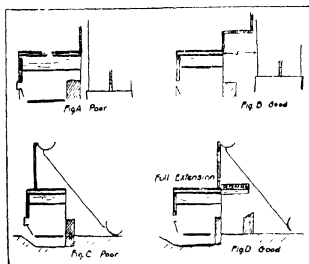
3. DOUBLE INCLINED STOKERS AND VERTICAL BOILERS
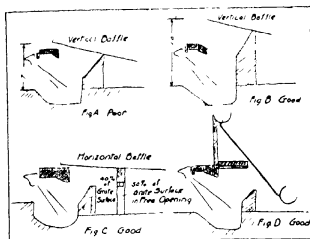
4 COMBINATION OF FRONT FEED STOKERS
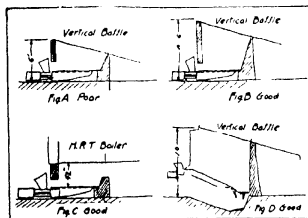
5. HEADROOM FOR UNDERFEED STOKERS
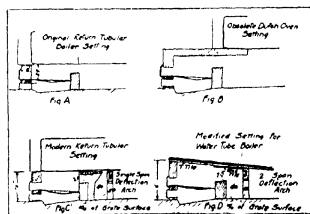
6 DEVELOPMENT OF HAND-FIRED FURNACE

PROPER AND IMPROPER DESIGNS OF FURNACES FROM STANDPOINT OF SMOKE PREVENTION

—*Steam.*

Osborn Monnett presents the sketches on page 304 as proper and improper designs of furnaces

Fig. *A* in sketch 1 is typical of the older practice in chain-grate settings, with low, short, flat arch, poor ignition and low capacity. The deadening effect of the bank of tubes is to extinguish the flame before combustion becomes complete, in the same manner that a wire netting will kill the flame from a gas burner, the result being a great deal of smoke. It must not be inferred, however, that mere length of flame-travel is always sufficient to insure a satisfactory setting. It has been found that on a long gas pass, unless some positive means are taken to cause a mixture, the gases frequently become stratified and do not mix, in which case the combustion cannot be complete

In Fig. 1-*B* the boiler has been raised to 10 ft under the header, and the ignition arch lengthened 5 ft, with full extension. This allows more flame-travel, but the setting still has some of the defects of the first one. The rich volatile matter may pass into the bank of tubes in an uninterrupted current in the front part of the furnace, while most of the oxygen necessary to burn the volatile matter is passing in at the back part. There is lack of mixture, and consequently incomplete combustion and low economy.

In Fig. 1-*C* the above defects are corrected by using a longer arch, setting the stoker farther under the boiler, decreasing the floor space occupied, and narrowing the furnace throat opening, so that the volatile gases and air mix in a high temperature zone, which usually completes combustion on a 10 ft setting Openings from 18 to 36 in have been tried with success, the smaller ones being high in maintenance A 30-in. throat opening is about the most satisfactory.

Another factor which has had a marked effect on the performance of the later chain-gate settings has been the height of the ignition arch at the grate. Where 11 inches was formerly the standard height for a flat arch, it has now been increased to 15 inches, and the slope of the arch has been increased to 2 or 3 inches per foot Where the arch is sprung against the furnace, it now sits 9 inches above the grate at the skewback, with a 9-inch spring, making 18 inches at the center of the arch.

Fig. 1-*D* shows a setting which may be considered ideal for a chain grate. 6 ft 6 in may be considered the minimum headroom allowable.

Sketch 2 shows a setting with a double-inclined (*V*) type of stoker. The short length of flame discharging directly into the bank of tubes is undesirable when the fire is being worked This type of stoker is often found installed in a seven-foot headroom, as in Fig. 2-*A*.

One of the safest arrangements is to provide a tile roof setting with an auxiliary bridge-wall, as in Fig. 2-*C*. This breaks up the current of gases, and insures mixture The importance of setting this type of furnace with maximum flame-travel is not always realized.

Sketch 3 shows vertical and Stirling boilers with double-inclined furnaces. It is a safe rule to get a full extension on this type of furnace and never resort to the flush-front setting.

Sketch 4 shows settings with a front-feed stoker The same points should be observed as regards flame-travel as with double-inclined stokers,

to get good results with vertically-baffled water-tube boilers. With a horizontal baffle it is a simple matter to use this type of stoker successfully. Sufficient headroom only is required to get the stoker under the front header. Sometimes piers or deflection arches are used. Where the free opening in such a setting does not go below 40% of the grate surface of the stoker, such construction is desirable.

Sketch 5 shows a different type of underfeed stoker, requiring different headroom. The Jones and Taylor types give excellent results with a headroom of 8 ft. 6 in. for a vertically-baffled boiler, and 7 ft. for a horizontally-baffled boiler. In the case of horizontal return tubular boilers these types of stokers can be installed with 42 in. from grate to shell. With stokers of the Taylor type, Fig. 5-D, a 10-ft. clearance is ideal.

Sketch 6 shows settings for hand-fired furnaces. Fig. 6-A is a setting which is fairly efficient commercially, but is very smoky with high volatile coals. The Dutch oven setting in Fig. 6-B was an attempt to improve the plain hand-fired setting. From a smoke standpoint, this Dutch oven setting is a poor combination. The high radiation from the brick-work above the fire has the effect of distilling the gases so rapidly that puffs of dense smoke will be made after every firing, in spite of all effort to prevent them. Fig. 6-C shows how to correct this defect, by baring the shell to the direct radiation of the fire. This increases the steaming capacity, and provides a high temperature zone back of the bridge-wall, where the gases must mix positively against the deflection arch, and so promote combustion. It is not practicable to combine a hand-fired coal-burning furnace with a vertically baffled water-tube boiler, but it is a simple matter to arrange such a furnace with a horizontal baffle, carrying out the same idea as in Fig. 6-C. The ordinary hand-fired, horizontally-baffled water-tube boiler furnace is covered with block tile, and has nearly all the defects of the Dutch oven shown. Fig. 6-D indicates how this can be overcome, by putting T-tile on the second row of tubes over the fire, thereby avoiding the radiating effect of a mass of fire-brick, and by installing a two-span deflection arch to break up the current of gases. There should be from 20 to 25% of the grate surface in free openings above the bridge-wall. The free opening from the back of the bridge-wall to the deflection arch should not be less than 40% of the grate area, while the free opening under the deflection arch should be 30% of the grate area. Hand-fired furnaces for high pressure work should be fitted with four air-syphon steam jets placed across the furnace above the fire-door.

The following deductions by the *Bureau of Mines* are from tests on a return-tubular boiler:

1. The operation at rating of a return tubular boiler, hand-fired, is possible without violation of smoke ordinances. However, it requires proper supervision, usually with attention to firing methods not given by the average fireman.

2. Smoke is prevented more easily by the coking method of firing than by the spreading method of firing.

3. The use of supplementary air immediately after firing tends to increase the overall efficiency and to abate smoke.

4. A brick arch directly over the fire and underneath the boiler shell results in lower overall efficiency and in the production of more smoke.

The down-draft type of furnace, illustrated in the adjoining cut from the *Heating and Ventilating Magazine*, is used in small installations to insure smokeless combustion. There are two fire grates, one above the other. The fresh coal is charged onto the upper grate, which is composed of water pipes, and the distilled gases pass downward through the incandescent fuel, and are intimately mixed with the heated air, coming up through the lower grate, which receives the incandescent coke falling from the upper grate
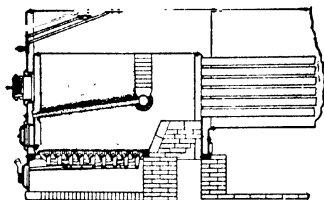
DOWN DRAFT FURNACE FOR SMOKELESS COMBUSTION
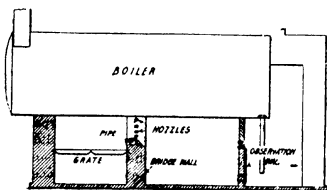
SMOKE PREVENTION FURNACE—*Iron Age*

The furnace illustrated above has been designed by *Anton Graf* to insure the complete combustion of the gases from the fuel, by the introduction of *preheated air* impelled by a steam jet A 4-in. air pipe is imbedded in the top of the bridge wall, which is curved to conform to the boiler shell.
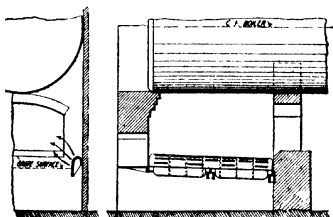
SIDE GRATE ADMITTING AIR OVER FUEL BED
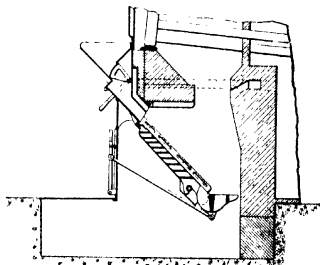
SIDE GRATE FOR SLOPING FURNACE   —*Power.*

The side grate for the prevention of clinker and the more thorough combustion of gases from volatile coals by the use of secondary air, shown above, is due to *Joseph Goder.* The amount of air passing through the

TABLE 1 - DIMENSION SHEET FOR DOUBLE ARCH BRIDGE WALL FURNACE																					
A	B	C	D	E	F	G	H	I	J	K	L	M	O	P	Q	R	S	T	U	V	W
42	120	28	19	42	42	22	18	42½	3½	6½	18	21	16½	9	15	27½	15	8	8	13½	8
42	140	28	19	42	42	18	44	4	15	18	24	18½	11	17	27	14	8	8	13½	8
48	120	30	20	42	48	24	18	42½	3½	18	20	19½	7½	15½	30	15½	9	8	9½	8
48	140	30	20	48	48	24	18	46½	4	16½	18	24	19½	9½	11½	28	17½	9	8	13½	8
48	160	30	20	54	48	24	18	48½	4½	15	18	26	19½	11½	19½	30	19½	9	8	13½	8
54	140	32	22	48	54	24	18	44½	4	16½	18	24	20½	11½	18	30	19½	8	9	13½	8
54	160	32	22	54	54	24	18	55½	4½	5½	18	24	20½	13½	20	30	21½	9	9	13½	8
60	140	34	22	60	60	26	18	53½	5	17	22½	26	22½	19	17½	33½	20	9	10	13½	8
60	160	34	22	66	60	26	18	60½	5½	15½	22½	26	22½	15	20½	30½	24	9	10	13½	8
66	140	34	24	60	66	28	18	56½	5	17½	28	28	24½	11½	22½	34	20½	9	11	13½	8
66	160	34	24	66	66	28	18	59	5½	17	22½	28	24½	13½	24½	36½	22½	9	11	11½	8
72	140	36	24	66	72	30	20	39½	3½	18	22½	30	24½	13½	20½	37	22½	9	12	13½	8
72	160	36	24	72	72	30	20	48½	6	17½	22½	30	24½	13½	26½	40	24½	9	12	13½	8
72	180	36	26	72	78	32	21	65	6	19	26	32	30	15½	27½	40	25	9	12	13½	8
72	200	38	26	78	78	32	21	70	6½	11½	26	30	30	11¾	29½	43	27	9	12	13½	8
84	160	38	26	72	84	32	21	64	6	20	26	33	14	27½	40	24	9	12	13½	8
84	200	38	26	78	84	32	21	69	6½	18½	26	36	33	1/6	29½	43	26	9	12	13½	8

Dimensions in inches except as otherwise noted

Plan Section Through X-X

45 Sq. Inches of Opening in Panel per Sq. Ft. of Grate
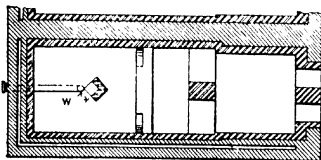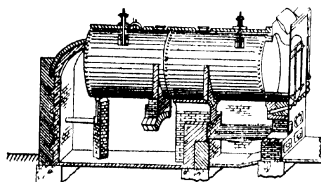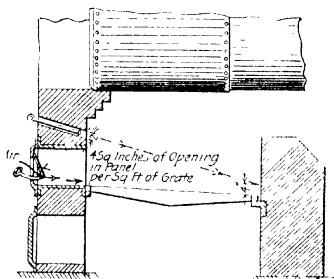
THREE STYLES OF TIPS

DETAILS OF STEAM JET AND PANEL DOORS
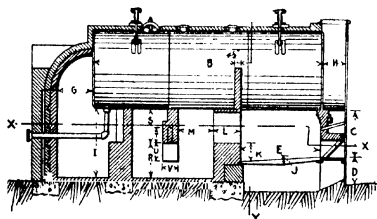
Longitudinal Section
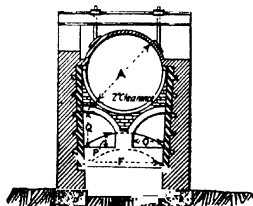
Front Section Through Y-Y

DOUBLE-ARCH BRIDGE WALL SETTING FOR TWO-COURSE BOILER

side grates increases when a higher resistance is offered by the thick fuel bed after firing, automatically taking care of the greater air requirements. Care must be taken that these grates are equipped with proper cooling ribs and air openings.

A **double-arch bridge-wall setting** for use with horizontal return tubular boilers, designed by the *Chicago Department of Smoke Inspectors* and described by *Osborn Monnett*, is shown in the cuts on page 308. The gases from the grate are divided before they pass over the bridge-wall by 'the double-arch shown in the front section, and are thoroughly mixed and exposed to high temperature as they pass through the two retorts thus formed   They are then further mixed and burned when they pass under a low single-span deflection arch back of the bridge-wall. The area through the double arch above the bridge-wall should be 25% of the grate area; that from the back of the bridge-wall to the deflection arch should be 45% of the grate area, and the area under it 50% of grate area. This setting is supplied with a panel door at the dead plate, discharging downward, as shown in the sketch, so that the air admitted is heated and mixed with the gases as it scrubs over the fire. Steam jets of the air syphon type should be placed above the fire-door and equally spaced on 18-in. centers, just enough steam being used to cause a good mechanical mixture of the air over the fire   Patented settings are also on the market which maintain the gases at a high temperature and mix them by the use of piers and wing walls, which are cheaper than the arch construction. For horizontal water tube boilers with vertical baffles the Chicago Department recommends that T-tiles be used to expose the bottom row of tubes to the fire for a short distance from the front header; that a high temperature zone be provided over and back of the bridge wall by the use of box tiles around the bottom tubes, from the T-tiles to a point several feet in front of the back header; that a deflection arch be placed back of the bridge wall; and that secondary air be provided by a panel door and a steam jet   All such arches must be of good brick, well laid, and air leakage through the setting prevented by asbestos or magnesia insulation.

FURNACE VOLUMES

E. B. Ricketts states that modern engineers favor larger furnace volumes, although comparison of data on actual installations does not show any pronounced increase in efficiency therefrom. He gives the following tables:

MAXIMUM *BTU* FIRED PER HOUR PER CU FT OF FURNACE VOLUME AT EFFICIENCIES OF ABOUT 80% WITHOUT ECONOMIZERS

Fuel-burning System	*BTU* per Cu Ft. of Furnace Volume
Pulverized coal	22,000
Chain-grate stokers	37,500
Underfeed stokers	64,000
Locomotives	70,000
Oil—steam atomization	85,000
Scotch marine boiler, hand-fired.	144,000
Oil—mechanical atomization	176,000

CUBIC FEET OF FURNACE VOLUME PER RATED HP. (10 SQ. FT. BOILER HEATING SURFACE)

Station	Chain-grate Stokers	Underfeed Stokers	Pulverized Coal
American Sugar—Baltimore..	2.00	..	...
Kansas City	2.57	.	...
Dalmarnock—Glasgow . .	3.10		...
Barking—London	3.87		...
Calumet	4.45		...
Waukegan	5.75	...	...
Dodge Bros	.	2.17	...
Seward	.	3 24	. .
Colfax	..	3.45	...
Springdale		3.95	
Hell Gate	.	4.23	. .
Gennevilliers—Paris	.	4.50	. .
South Meadow	.	4.56	. .
Delaware		4 80	...
Lakeside	.	.	4.66
River Rouge	.		4 98
Cahokia	.	.	6.52

OLDER STATIONS

Waterside		1.05	..
Essex		1.95	..
Muscle Shoals		2.19	...
L. Street		2.43	...
Connors Creek		2.72	.....

Powdered coal is seen to require the largest volume, as long flame travel must be provided to consume it with little excess air, while Scotch marine boilers will burn satisfactorily seven times as much coal per cu. ft. of furnace volume. Mechanical atomizing oil burners operate with minimum furnace volume, 265,000 *BTU* per cu ft. per hr. having been fired with a White-Foster burner at 76% efficiency, due to thorough mixing and intense flame. Lump low-volatile coal also requires little volume, as most of the combustion takes place in or near the fuel bed. In underfeed stokers with continuous ash discharge, a large part of the combustion takes place on the grate and a fairly uniform mixture is delivered to the furnace, so that less furnace volume is required than with chain grates, where there is deficient air in the front or ignition zone, and excess air at the rear. An ignition arch is always provided with chain grates, and frequently a reverse arch over the rear, and in some cases a third arch over the center of the combustion chamber to mix the gas streams from the three main divisions.
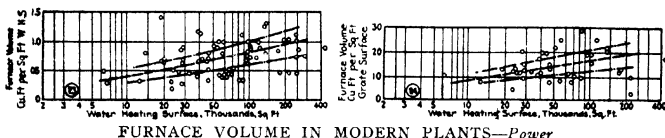
FURNACE VOLUME IN MODERN PLANTS—*Power*

The above charts, by *John G. Fairchild,* show the ratios of furnace volume to heating surface and grate surface in a number of modern plants, the dotted lines representing the mean and values 25% above and below.

F. W. Dean condemns the tendency to set boilers high, except with the transverse-baffled water-tube boiler, where the streams of combustible gas and oxygen are parallel and have only a short path in a low-set boiler before they strike the tubes. He states that high settings are often arranged with the idea that air may enter where it will do some good by encountering combustible gases, and little attention is given to the chance that it will enter where it does no good and merely cools off the boiler. Even with small space above the fire and small volume for combustion the best results can be obtained with proper firing and air properly admitted at the right point. This is shown in the Scotch boiler, with small space above the middle of the fire and none at the sides, in which air is admitted at the bridge wall to convert CO of 15% at a point 16 in. in front of the bridge wall to 15% CO_2 16 in. back of the bridge wall. Horizontal space is as good as vertical, and with too large areas for the gases to pass through, there is less prospect of the excess air in one place meeting the excess combustible gases in another.

Two-Stage Combustion.—*C. E. Stromeyer* discusses the possibility of obtaining maximum absorption without the destructive effects of high furnace temperatures on boiler tubes. In the figure, the solid curve to the right represents the temperature drop of the gases in passage through boiler, superheater, economizer and air heater, for an initial furnace temperature of 3000 to 4000° F., representing perfect combustion and little excess air. If, however, the coal could first be burnt to CO, and the gases passed over heat-absorbing surface and then burnt to CO_2 and passed over additional boiler surface, the maximum temperature would not exceed 2500° F. in either combustion chamber, the temperatures anticipated being shown dotted in the figure. Another method would be to withdraw from the chimney, as by the fan shown in the sketch, 33% of the 140° F. gases leaving the air heater, and introduce them below the grates. These gases would amount to about 50% of the heated air supplied to the furnace at 400° F. and the mixture would produce a furnace temperature of about 2700° F., which is high enough to insure complete combustion without injuring the boiler. He states that this would also reduce the chimney loss from 3% to 2% or less, although it would call for more boiler heating surface than with furnace temperature at 4000° F., and for fan power.
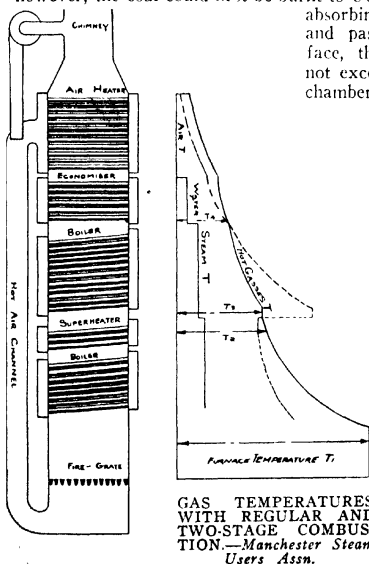
GAS TEMPERATURES WITH REGULAR AND TWO-STAGE COMBUSTION.—*Manchester Steam Users Assn.*

Henry Dieterlen describes the Kestner system of two-stage combustion, designed to reduce to a minimum the air employed for combustion, and yet afford complete combustion while maintaining a moderate furnace temperature. It includes a semi-producer type of continuous furnace designed to regulate the coal and air supply, a primary boiler to cool the gases to the lowest temperature (about 1100° F.) which will permit reignition, a device for mixing secondary air with the gases thus cooled, preferably by the use of baffles, and a secondary boiler element wherein the heat from the completed combustion is absorbed. Fig. *A* shows a Stirling boiler with a mixing chamber between the first and second boiler passes, and *B* an inclined water-tube boiler with four vertical passes and the mixing chamber between the first and second. With thorough mixing, if one finds 5% O_2 at the damper, he can reduce the air till he gets 3% or 1% O_2, although reducing it sufficiently to give zero O_2 may result in smoke. The best practice is between these two extremes, giving say 19% CO_2, zero CO, and ½% O_2 in the chimney gases.
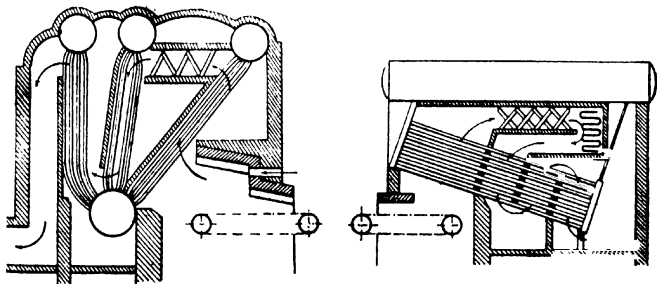
KESTNER TWO-STAGE COMBUSTION—*Chaleur et Industrie*
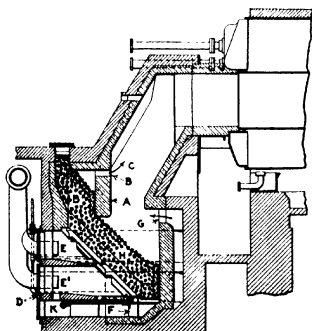
C. BERGMAN SYSTEM OF
"HALF-GAS" FIRING
—*Elec. World.*

The **Bergman** system of "half-gas" firing is based on the idea that each step in combustion—drying, carbonization, gasification and burning—should be completed independently, with successive rises in temperature. Fig. C shows a furnace in which a hanging bridge *A* separates the drying chamber *B* from the rest of the fuel bed, and there are separate adjustable air supplies to the active bed; *E* to the volatilization zone, and *E'* to the section where the coke is gasified and the fixed carbon burned. Secondary air enters at *G* and *C*.
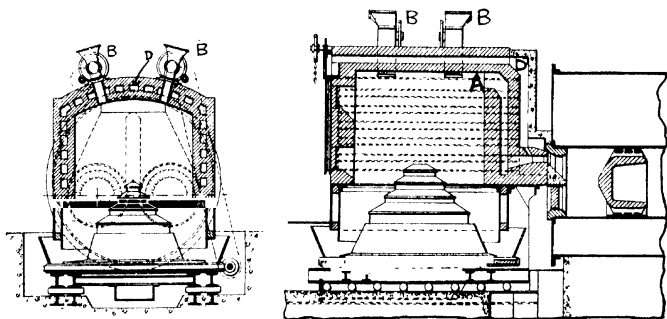
D   MILLS SYSTEM OF "HALF-GAS" FIRING—*Elec World.*

Fig. D represents an external furnace, resembling a gas producer, placed in front of a Lancashire boiler, as built by *E. C. Mills* in England. Coal is fed from the hoppers *B* to the revolving conical step grate, while the partly-burned gas escapes through *A* to the combustion space of the boiler. Secondary air flowing in through a series of passages *D* in the top and sides of the "producer" is thus pre-heated, saving the heat which would be lost in a separate producer   The combination is reported to have produced 10 to 11 lb steam per lb of coal, with 18% saving over ordinary methods of firing.

MECHANICAL STOKERS AND THEIR OPERATION

Commercial stokers fall into three main groups, the chain grates, the overfeed stokers and the underfeed stokers. In the first, the coal is carried horizontally in a layer on a continuous jointed web, which passes over rollers and returns underneath. It is fed from hoppers, ignited and exposed to distillation at the front, and slowly consumed as it travels to the rear.   Such stokers are particularly adapted for low-grade free-burning coals from the Central States, averaging 35% volatile and 15% ash. They operate efficiently and with a minimum of smoke, up to 200% boiler rating, but with low-ash fuels are subject to overheating

The *Stoker Manufacturers Association* defines an overfeed stoker as one wherein fuel is fed onto grates above the point of air admission, and classifies them as follows: Front-feed inclined stokers, where fuel is fed from front onto a grate inclined downwards toward the rear of the stoker; double inclined side-feed stokers, where the fuel is fed from both sides onto grates inclined downwards toward the center line of the stoker; chain or traveling-grate stokers, where the fuel is fed to the stoker from the front onto a moving grate forming an endless chain

In underfeed stokers the fuel is introduced at a level below the point of air admission, utilizing the gas producer principle. The green coal is fed to the lower layer of the fuel bed, and is gradually pushed up and coked, giving up its volatile constituents and becoming incandescent by the time it reaches the top layer   The grates are sloping, and the fuel after

reaching the upper zone burns to ash as it works down to the refuse dump. Underfeed stokers are largely used in heavy-duty installations, and are often employed to drive boilers up to 400% of their nominal ratings.

Edw. W. Jones outlines the fields of the several types of stokers as follows · **Underfeed stokers** are especially adapted for low-ash coking and caking Eastern bituminous coals, and to some extent for high grade lignites They can be built in very large sizes, have high capacity and are suitable for varying loads, but the agitation of the fuel unfits them for use with anthracite or coke braize or with high-ash or low-fushion-ash coal, as the ash is forced into the burning zone and is fused into large clinkers. The **Inclined gravity-feed** types have a field in burning Eastern bituminous coals in relatively small units, on reasonably constant loads, but high-ash coals are troublesome, and anthracite and coke braize cannot be burned successfully without admixture of other coal, due to avalanching. Double-inclined models can be used for fuels which are difficult to ignite. The **chain grate** is desirable for bituminous and sub-bituminous coals mined west of the Indiana-Ohio line, as the fuel bed is carried continuously without agitation or formation of clinker. With low-ash Eastern coals the residual bed of ash is not thick enough to protect the links, when near the bridge wall, from the furnace heat Caking coals tend to form lumps that burn slowly and are rejected to the ash pit as coke, but anthracite and coke braize can be handled The capacity and flexibility are not great, except when forced draft is used

Joseph G Worker states that any mechanical stoker will burn practically every coal with some degree of success, but that no stoker is a commercial success with every coal. Applications to various groups of coal are summarized by him as follows The high-grade bituminous coals of Pennsylvania, West Virginia and Virginia, are low in volatile and ash and high in carbon, and swell on heating and tend to cake into a solid mass. Side-feed and front-feed stokers provide sufficient agitation to keep the bed broken up in a uniform and porous condition, unless it becomes too thick. With 0.50 in natural draft, up to 35 lb per sq ft of grate surface per hr. can be burned, and more with forced draft, if the thickness is not over 6 in With underfeed stokers, beds of 24 in and thicker are used, broken up by the pushers, and combustion rates of 60 lb can be maintained for long periods and 80 lb for 3-hr peaks A properly-banked unit can be brought up to 200% rating in 4 or 5 min Traveling grates are not adapted to Eastern coal, unless agitating devices are applied at the front part of the grate, to prevent the formation of a solid mass of coke.

The high-volatile or "Pittsburgh" coals, from Western Pennsylvania, Eastern Ohio and parts of West Virginia, can be burned on overfeed stokers at rates of 30 to 35 lb, and peak loads of 40 to 45 lb for two or three hours with furnace draft of 0 5 to 0 6 in Furnaces with considerable brickwork and long flame travel are required for smokeless combustion. Underfeed stokers give combustion rates of 40 to 50 lb, and 70 to 75 lb. for 3-hr. peak loads. Thick beds provide for distillation, and large combustion spaces must be used Chain grates can be used unless the caking tendency is too strong, but should be ten feet or more in length in order to burn out the carbon in the ash

"Free-burning" Michigan coals can be burned on overfeed stokers if not so much agitated as to produce clinker. Overfeed stokers give com-

bustion rates of 40 lb., the duration of peak loads in excess of 60 lb. per sq. ft. per hr. is limited by refuse removal Chain grates handle combustion rates of 30 to 35 lb., and 40 lb. for long peak loads, with 0 5 to 0 6 in. furnace draft, and without caking

Coals from Illinois, Indiana, Missouri, also Washington and Oregon, are generally non-caking, and burn best on the overfeed type of stoker with just sufficient grate motion to cause a continuous feed without producing clinker Coals with less than 15% ash are burned on overfeed stokers at combustion rates of 30 lb., and 35 to 40 lb for two or three-hour periods (0 45 to 0 5 in furnace draft) and 45 lb for short periods, using hand cleaning at maximum rates The use of underfeed stokers is recent, at combustion rates of 40 to 50 lb., and 60 to 65 lb for long peaks, but water boxes are required at the clinker line for the higher rates.

Commercial Iowa coals are of low grade, down to 8000 *BTU* per lb. as fired The arch construction of overfeed stokers leads to clinker trouble at combustion rates over 20 lb., for which a draft of 0 35 to 0 4 in is also required Underfeed stokers of the self-cleaning type, without firebrick arches and with water-boxes for prevention of clinker adhesion, give rates of 35 to 40 lb and 50 to 55 lb for 3-hr peaks Forced-draft traveling grates are satisfactory.

Southern coals, from Kentucky, Tennessee and Alabama, are high-grade and are generally free-burning, although some show a tendency to cake, and all require liberal combustion chambers for smokeless operation. Overfeed stokers give combustion rates of 30 to 35 lb., or 40 lb for short periods, with 0 5 to 0 6 in. draft in the furnace, although the low ash necessitates care to prevent burning grates Underfeeds give rates of 50 to 60 lb., and 70 to 75 lb. for peaks, the feeding action preventing caking. Chain grates are unsatisfactory for such coals as cake

Colorado lignite can be ignited on overfeed stokers with suitable arch construction, and burned at rates of 20 to 25 lb. With underfeeds the heavy bed at entrance dries the fuel, and 30 to 40 lb per sq ft. can be burned, and 55 to 65 lb for short peaks, in spite of some clinkering trouble. Chain grates can be used if the fuel is not too coarse Colorado high-volatile bituminous coals, both caking and non-caking, burn satisfactorily on overfeed stokers, at a 30 lb rate or 35 to 40 lb for short intervals, with furnace draft 0 5 to 0 55 in, while underfeed stokers are satisfactory with large combustion chambers

Dakota lignites, crushed to small size, can be burned on chain grates with special arch constructions, or underfeed stokers with short ignition arches over the front of the furnace, permitting combustion rates of 30 to 40 lb., and 55 to 60 lb for peaks

Edward H. Tenney discusses the limitations in the use of Mid-West coals, as those from Southern Illinois, on mechanical stokers. The high volatile (say 31%) calls for a good distribution of air in the furnace space, while the ash, which may be 15%, tends to produce stratification of the air supply. The *Bureau of Mines* has determined that when burning coal at the rate of 50 lb per sq ft. of grate area per hr, with 50% excess air and not over ½% of combustible in the flue gases, Illinois coals require 11.9 cu. ft. of combustion space per sq. ft of grate area as compared with 4.8 for Pocahontas coal The large volumes of gas handled require careful boiler baffling to maintain uniform velocity, and also ample draft. *Tenney* states that for natural-draft chain grates the maximum capacity with Mid-West coals is 45 lb. per sq. ft. per hr., above which the ash-pit loss increases excessively and it is almost impossible to maintain ignition. With

The following setting heights are recommended by the Joint Committee of *American Boiler Manufacturers Association* and the *Stoker Manufacturers Association.*

SETTING HEIGHTS FOR VARIOUS TYPES OF BOILERS EQUIPPED WITH STOKERS

Min—absolute minimum.   P M—preferred minimum i e the minimum heights recommended

Type of Boiler — Setting Height Measured from Floor Line to	TYPE OF STOKER TO BE INSTALLED													
	Multiple-Retort Underfeed (Taylor, Westinghouse, Riley, Jones & C, Detroit)		Single-Retort Underfeed Type E		Jones Single-Retort, Detroit Single-Retort		Side Over-feed (Murphy, Detroit)		Front Over-feed (Roney)		Chain Grates — Natural Draft		Chain Grates — Forced Draft	
	Min	P M	Min	P M	Min	P M	Min	P M	Min	P M	Min	P M	Min	P M
Water-Tube: Horizontal — Bottom of header above stoker	10'	12'	10'	12'	8'	10'	8'	11'	8'	10'	10'	12'	12'	14'
Inclined (Hor. M D) — Center of mud drum	7'	8'	6'	8'	6'	8'	5'	7'	6'	8'	6'	7'	7'	8'
Inclined (Vert. M D) — Top of mud drum	5'	6'	5'	6'	3'6"	6'	3'6"	5'	3'6"	5'	3'6"	5'	6'	8'
Vertical (Hor. M.D.) — Center of mud drum	3'	4'	3'	4'	3'	4'	3'	4'	3'	4'	3'	4'	3'	4'
Vertical (Vert M D) — Top of mud drum — 150 HP.	4'6"	5'	4'6"	5'	4'6"	5'	3'3"	3'3"	3'6"	4'6"	4'1"	4'7"	5'	5'6"
250 HP.	5'6"	6'	5'6"	6'	5'6"	6'	3'3"	3'3"	3'6"	4'6"	4'1"	4'7"	5'	5'6"
300 HP.	6'6"	6'6"	6'6"	6'6"	6'6"	6'6"	3'3"	3'3"	3'6"	4'6"	4'1"	4'7"	6'	6'6"
Horizontal Return Tubular, Under side of shell — 72 In.	8'	10'	8'	10'	7'	10'	7'	9'	6'	8'	7'	8'	8'	10'
84 In.	8'	10'	8'	10'	7'	10'	7'	9'	6'	8'	7'	8'	8'	10'

forced-draft chain grates 60 lb. can be reached before clinker and temperature difficulties make operation prohibitive. Natural-draft overfeed stokers are limited to a 30-lb. rate, beyond which avalanching occurs; with forced draft 60 lb. per sq. ft. can be burned. Underfeed stokers with multiple retorts and forced draft are responsive to variations in load, and will handle 900 to 1000 lb per retort per hr. continuously, or 1400 lb. for short periods   At high overratings the fuel bed may become fused over near the dump plates, holding up combustion till this condition is rectified.

   J. G. Worker suggests that in planning stoker installations, consideration be given in the choice of equipment to necessity of meeting high overloads at times; the type of fuel available, whether high or low in volatile, ash and sulphur; the draft conditions in a plant already installed; and possible limitations in space for ash tunnels, extension furnaces, etc.   The data called for below will enable the manufacturer to analyze the needs and to recommend equipment to meet the four requirements just stated.

DATA REQUIRED BY STOKER MANUFACTURER

Boilers:
   1. Type   Rated HP.   Tubes high, or Class, or Dia. (*HRT*)
          Tubes wide   Tubes length
   2   Centerwall   Alleyway   Sidewall   Furnace
          Floor line to   Mud drum (center line), or Header, or Shell (C.L.)

Stack:
   3. No. of stacks   Brick or Steel
   4. Ht. above present boiler room floor   Inside Dia. at top
          Boilers served   Total HP. served
            (each stack)   (each stack)
   5. Connected to boiler by   Breeching or direct

Stoker Setting and Applications:
   6. Old or new boilers? If old, can they be reset?
          Can floor be lowered?
   7. What local conditions prevent the best application?
   8. Will ashes be taken out   Floor or Basement?
                              Conveyor or Car?
   9. Do you contemplate installing future stokers?
          How many?   Relation to this installation?
   10. What drawings do you want for preliminary study?

Fuel to be Used
   11. Name   Where Mined   *BTU* (as fired)
   12. F C.   Vol.   Moist   Ash   Sulphur

Operating Service:
   13. Best economy desired at———rating   What will be maximum
          rating?   Duration (hrs)   Avg. daily rating.
   14. Remarks regarding the character of service and plant organization.
   15. Steam pressure of plant.   Superheat: Back Pressure:

Stoker Drive: (Do you want stoker driven by)
   16. Engine   Turbine and Gear   Motor

Forced Draft Fan Equipment: (How many fans do you want, and how driven?)
   17. Number of Fans (   )   Driven by
          (   ) Turbine and Gear   (   ) Motor   (   ) Engine

Deliveries Required:
   18. Stokers and Equipment ——— Months.

J. P. *Sparrow* gives the following list of coals suitable for different types of stokers, in which the names refer to types rather than to individual makes.

COALS SUITABLE FOR VARIOUS TYPES OF STOKERS

LOCATION OF MINE	ANALYSIS						FUSION Temp °F.	TYPE OF STOKER	REMARKS
	Mois-ture	Vola-tile Matter	Fixed Carbon	Ash	Sulphur	BTU			
Cambria Co., Pa	3 6	20 3	68 6	7 5	1 88	13710	2179	Taylor	Very bad Clinkers.
Fulton Co., Ill.	15 0	33 1	36 8	15 1	2 82	9680	2184	Taylor	Clinker Trouble at Dump Grate, Side Wall Protected by Steam Jets.
Westmoreland Co., Pa	2 2	35 2	50 0	12 6	2 37	12419	2223	Taylor	Bad Clinkers.
Raleigh Co., W. Va	4 2	19 9	70 8	5 1	0 83	14019	2295	Taylor	Some Trouble with Clinkering and Bridging Over Dump Grates.
Borderland, W. Va	7 6	35 9	49 8	6 7	1 15	12647	2297	Taylor	Forms Small Brittle Clinkers.
Raleigh Co., W. Va	2 8	17 9	72 5	6 8	0 92	13889	2303	Taylor	Trouble with Clinkers Bridging Dump Plates and on Side Walls
Caryville, Tenn	4 0	33 6	47 4	15 0	1 57	11605	2304	Taylor	Hard Clinkers.
Raleigh Co., W. Va	4 4	17 5	70 9	7 2	0 85	13482	2306	Taylor	Very Large Clinkers on Side and Bridge Walls
Cambria Co., Pa	1 8	25 3	64 7	8 2	1 36	13795	2335	Taylor	Some Trouble from Clinkers.
Cambria Co., Pa	2 6	19 5	69 8	8 1	1 92	13837	2361	Taylor	Very Bad Clinkers
Westmoreland Co., Pa	2 6	35 0	51 7	10 7	1 87	12713	2384	Taylor	Bad Clinkers
Mercer Co., Pa	5 4	34 0	47 5	13 1	3 40	12291	2390	Taylor	No Serious Clinker Trouble
Glen White, W. Va	2 4	17 7	73 6	6 3	0 72	14112	2394	Taylor	No Clinker Trouble.
Pocahontas, Fayette & Raleigh Cos., W. Va.	4 2	17 6	72 1	6 1	0 66	13918	2405	Taylor	No Clinker Trouble.
Somerset Co., Pa	1 4	22 2	71 6	4 7	1 11	14565	2408	Taylor	Large Clinkers on Side and Bridge Walls.
Somerset Co., Pa	1 0	17 7	70 5	10 8	2 14	13689	2414	Taylor	Good Coking, Free Burning, Forms Large Vitreous Clinker.
Pittsburgh District	2 4	32 4	54 3	10 9	1 80	13006	2427	Taylor	Very Little Trouble with Clinkers.
Cambridge Ohio	5 0	37 7	49 3	8 0	2 75	12521	2435	Taylor	Forms Thin Brittle Clinkers
Somerset Co Pa	0 6	27 8	71 6	10 0	1 89	13601	2468	Taylor	Forms Large Clinkers
Cambria Co., Pa	0 2	25 4	63 2	9 2	2 67	13603	2534	Taylor	Slight Clinker Trouble above 200% Rating.
Glen Riche, Clearfield Co., Pa.	1 5	22 4	69 5	6 6	1 87	14232	2554	Taylor	No Clinker Trouble.
Cambria Co., Pa.	2 1	24 1	64 8	9 0	1 91	13480	2661	Taylor	No Trouble
Cambria Co., Pa.	1 6	25 4	65 5	7 5	1 36	14022	2684	Taylor	No Clinker Trouble.
Washington Co., Allegheny Co., Pa	0 3	32 2	57 1	10 4	1 06	13282	2290	New Roney	Bad Clinkers.
Washington Co., Pa	3 7	27 7	56 2	12 4	1 45	12540	2363	New Roney	Bad Clinkers.

	4.8	35.8	46.3	13.1	1.54	11085	2239	Roney	Very Thin, Soft Clinker, Gives
Rock Springs, Wyo									Serious Trouble.
Barnsboro, Cambria Co., Pa	2.6	23.4	66.4	7.6	1.75	13928	2379	Roney	Clinkers Part of the Time
	2.6	24.1	63.5	9.8	1.61	13414	2430	Roney	
	3.2	22.7	66.0	8.1	1.95	13658	2444	Roney	
Glen Richie, Clearfield Co., Pa	2.1	24.1	64.8	9.0	1.91	13480	2661	Roney	No Trouble
Barnsboro, Cambria Co., Pa	2.6	23.4	66.4	7.6	1.75	13928	2379	West U F	Clinkers Part of the Time
	2.6	24.1	63.5	9.8	1.61	13430	2430	West U F	
	3.2	22.7	66.0	8.1	1.95	13658	2444	West U F	
Westmoreland Co., Pa	2.2	35.2	50.0	12.6	2.37	12419	2223	Riley	Bad Clinkers.
	2.6	35.0	51.7	10.7	1.87	12713	2384	Riley	Bad Clinkers
Glen Richie, Clearfield Co., Pa	2.1	24.1	64.8	9.0	1.91	13480	2661	Riley	No Trouble
Washington Co., Pa	0.3	32.2	57.1	10.4	1.06	13282	2290	New Murphy	Bad Clinkers
Allegheny Co., Pa	4.0	32.3	52.3	11.4	1.40	12604	2366	New Murphy	Only a Little Trouble from Clinkers
West Virginia	1.4	18.5	74.6	5.5	0.84	14483	2339	Murphy	Clinkering Fair—69.4% Eff—Furnace Temp 2400 to 2450° F
Fayette Co., W Va	1.2	17.6	75.2	6.0	0.64	14397	2471	Murphy	Very Little Clinkers—65.0% Eff Furnace Temp 2100 to 2400° F
Wood Co., W Va	1.4	33.3	58.2	7.1	0.55	13651	2800	Murphy	Good, No Clinkers—71.1% Eff Furnace Temp 2325 to 2450° F
Illinois	8.8	34.0	39.4	17.8	3.10	10231	2032	Cham Grate	Lots of Clinkers, But Very Little Trouble
Madison Co., Ill	12.0	33.0	39.4	15.6	4.36	10145	2091	Cham Grate	
Illinois	9.8	34.4	38.1	17.7	5.11	10193	2157	Cham Grate	
Christian Co., Ill	13.6	30.9	37.8	17.8	5.04	9662	2179	Cham Grate	
Sangamon Co. Ill	14.2	31.4	38.9	15.5	4.40	9718	2179	Cham Grate	Plenty of Clinkers But No Trouble —700 HP Max
Illinois	6.0	85.2	46.7	12.1	1.98	11659	2253	Cham Grate	Plenty of Clinkers But No Trouble —800 HP Max
Vigo Co., Ind	10.2	33.8	38.4	17.6	3.99	10291	2256	Cham Grate	Plenty of Clinkers But No Trouble —800 HP Max
St. Clair Co., Ill	10.8	33.4	37.9	17.9	5.04	9910	2291	Cham Grate	Lots of Clinkers But No Trouble
Saline Co., Ill	6.8	31.8	50.6	10.8	3.36	12020	2297	Cham Grate	Plenty of Clinkers But No Trouble —960 HP Max
Barnsboro, Cambria Co., Pa.	2.6	23.4	66.4	7.6	1.75	13928	2379	Cham Grate	Clinkers Part of Time
	2.6	24.1	63.5	9.8	1.61	13414	2430	Cham Grate	
	3.2	22.7	66.0	8.1	1.95	13658	2444	Cham Grate	
Carthage, N M	1.2	37.3	45.6	15.9	1.01	12135	2559	Cham Grate	No Clinker Trouble
Cambria Co., Pa	1.2	20.8	68.3	9.7	2.48	13803	2468	Hand Fired	No Clinker Trouble.
	1.6	23.8	66.6	8.0	1.87	13989	2541	Hand Fired	
	1.4	22.5	67.3	8.8	2.05	13806	2570	Hand Fired	
Somerset Co., Pa	2.6	16.3	71.2	9.9	1.25	13428	2547	Hand Fired	No Clinker Trouble.
	2.4	16.4	70.6	10.6	1.57	13269	2577	Hand Fired	

Drawings
19. If possible furnish the following drawings:
   (*a*) Boilers and boiler settings as installed.
   (*b*) Beams and columns adjacent to boilers.
   (*c*) Details of basement, tunnel or pits under boilers.
   (*d*) Location of auxiliary equipment, piping, etc, that may inter-
   fere.

After determining the general type of equipment, the following should
be given joint consideration by the purchaser and the manufacturers of the
boilers and stokers:
1. Height of the boiler above the floor line, or height of boiler set-
ting.
2. Setting of the stoker
3. Combustion space necessary for the coal to be used
4. Design and location of the breeching
5. Size and location of the stack.
6. Area of gas passages through the boiler.
7. Area of damper openings
8. Facilities for cleaning soot off the boiler baffles and boiler tubes.
9. Grade of fire-brick to be used in the furnace construction
10. Size of walls of boiler and furnace setting.
11 Size and grade of fire-brick for arches, if used.
12. Method used to control dampers.
13. Construction of ash-pit and facilities for disposing of the ash.
14. Method of conveying coal to the stoker hoppers
15. Location of fans
16. Design and location of air ducts.

An arrangement is preferable whereby the purchaser assumes the erec-
tion, with the aid of a superintendent furnished by the manufacturer at so
much a day. If, however, the manufacturer is asked to bid on erection, he
should be given information as to location of boiler plant in building,
hauling conditions from station, etc., and the brick work, foundations, and
air ducts should be furnished by the purchaser or a general contractor.

Theoretically, the capacity of a stoker as a heat producer should be
ascertained from the rate of coal
combustion, the combustible left in
the ash, the CO_2 percentage and the
draft required.   In practice it is
judged by the steam production in
the boiler, which is affected by the
type and condition of the boiler, the
baffles, setting, breeching, stack, air
ducts, etc., as well as by the stoker
design and operation.   Since stoker
manufacturers are asked to make
overall guarantees which are affected
by all these factors, full information
should be given about them.

Jos. G. Worker gives, in Fig. A,
a comparison of the performance of
1925 type of stoker with those in-
stalled two, ten and fourteen years
earlier.
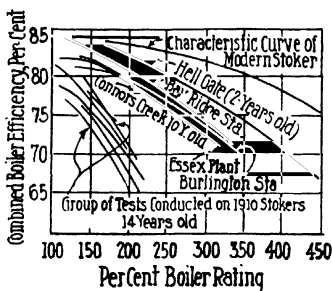
A. PERFORMANCE OF OLD AND
     NEW TYPE STOKERS

CHAIN GRATES

T. A. Marsh discusses the development and use of the modern chain grate with its progressive combustion, the moisture being vaporized as the coal is fed into the furnace, after which the volatiles are distilled and burned as gases, followed by the burning of fixed carbon, the discharge of the ash over the rear and the automatic cleaning of the grate air space for a repetition of the process Chain grates were first developed for fuels which were high in volatile, free-burning, clinkering (requiring undisturbed fuel bed), and high in ash (requiring continuous discharge). The chain is protected from heating by adequate ventilation. Modern adjustable ledge plates afford a proper rubbing seal with the stoker chain. The fuel retarder can be raised or lowered to hold a definite air seal with the fuel bed, and is used in connection with the bridge wall and a fixed water back connected into the water circulation of the boiler The use of longitudinal skids in place of rollers reduces sifting through the grates from 5 to 10% down to 1 or 2%. Modern chain-grate furnaces have 2 cu ft of furnace per developed HP, permitting driving of boilers at high rates without smoke or heavy loss of unburned hydrocarbon. Chain grates are used to drive boilers at rates of 200%, with induced or natural draft, using furnace drafts of 0 50 to 0 60 in, and combustion rates of 40 to 45 lb per sq ft. of grate surface per hr, with 1 sq ft grate surface per 30 sq ft. boiler surface, but forced draft with five or six compartments at various pressures is necessary if still higher ratings are to be obtained with bituminous coal Such stokers are 12 to 20 feet long, with width slightly less than that of the boiler-furnace The blast pressure rarely exceeds 2 in, even at a combustion rate of 55 to 60 lb. of coal per sq. ft of grate surface per hr, the highest pressure being usually carried in the second and third compartment, where the fuel bed is completely ignited and maximum combustion should take place Stokers installed for the burning of the Central States high-volatile coals have ignition or combustion arches set about four feet above the grate at the front end, and somewhat higher at the inner end These arches cover approximately 50% of the length of the stoker, are of the suspended type, and are made from high-grade refractory material Stoker installations for the burning of the low-volatile high-carbon bituminous coals of the Eastern States use a shorter arch, covering about 30% of the stoker length but set at practically the same height above the grate as for the high-volatile coals Arches set at this distance above the grate require a short ignition arch, 12 to 18 in in length, at the stoker gate, and set 18 to 24 in above the grate. To prevent formation of clinkers at the fire line on the side walls, special fire-brick blocks are used, cooled by air from the blast duct, or side-wall water boxes, either connected to the boiler or independent. Even some free-burning coals require agitation to break up crusting or caking action. Fires 3 to 6 in in thickness of No 3 buckwheat or coke breeze can be carried with sufficient blast in the first and second compartments to cause a gentle boiling or dancing of the fuel bed, provided careful regulation is employed to prevent the formation of CO. Continuous high overloads can be maintained with forced draft, at 55 to 60 lb. per sq ft grate surface per hr., while the same stokers can be operated efficiently under natural draft when burning 10 to 35 lb. A cold boiler can be put on the line in 45 min. from the time of lighting the fires. The boiler can be

operating at 150% of rating in 5 min. from the time it goes on the line, or it can be operating at 200% of rating in 7 min. With the ordinary short-banked fire, which consists of a bed of coal 3 to 4 ft. in from the stoker gate, the remainder of the grate being bare, the boiler can be brought up to 200% rating within 25 min., while with the long bank, in which 50% of the grate is covered with fire, the boiler can be brought up to 200% rating within 6 to 8 min.
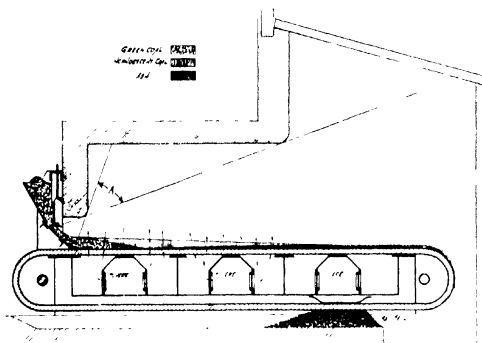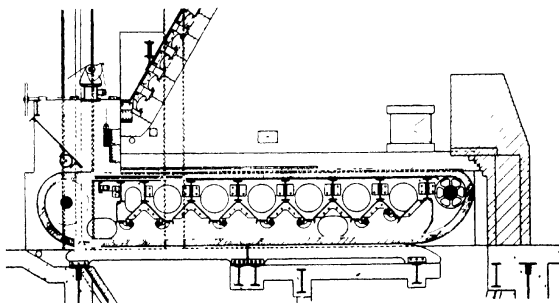
COXE CHAIN GRATE

ILLINOIS FORCED-DRAFT CHAIN GRATE

The Coxe Traveling Grate Stoker has two cast-iron side frames connected by sheet-steel bottom and end plates and wind boxes. Air is admitted into the wind boxes, in the sides of which are tuyeres controlled by sliding dampers which regulate the distribution and pressure in the different wind boxes and zones of the fuel bed. The grate is composed of cast-iron keys assembled on malleable iron dovetails bolted to carrier bars, which span the side frames and are fastened at each end to links of heavy drop-forged chain riding on wearing strips. Sprockets keyed to the drive shaft, usually located at the rear end of the stoker, provide the means for drawing the grate through the furnace. The other shaft and idler sprockets are at the front end of the stoker with bearings so located in the side frames as to permit the regulation of chain tension. An adjustable feed gate controls the thickness of the fuel bed. When burning low-volatile fuel a Dutch oven extension is usually employed in which the ignition and combustion arches may be either of the sprung or flat suspended type, and in some cases a water-cooled arch is used, the suspension members of which are pipes through which the feed water is circulated. The use of different pressures under different parts of the grate makes it possible to reduce the air through the thinner part of the bed at the rear, or to close the rear completely at low rating, and obtain high combustion rate and good ignition in the front. While originally designed for fine anthracite, the stoker has been applied successfully to practically every type of fuel

The Illinois Forced-Draft Chain Grate has a wind box running the entire length of the active grate surface, and located in one or both side walls. The side wall is divided into 2-ft. sections, each with a circular-plate opening into the wind-box, which can be locked into any position. The links are 9 in. long, 3¼ in. wide, 4 in. deep, with air slots on one side and the top face, and are connected by twisted-steel chain rods. A baffle is cast on each link, reducing siftings to the minimum, while a vertical fin prevents leakage of air along the chain. The grate is driven from the front, placing the top in compression, and there is a certain amount of rotation of adjacent links which shears off any slag deposits. The draft consumption does not exceed 1% of the total boiler horsepower. Bituminous coals are ignited by an Illinois Flat Suspended Arch, but with anthracite, coke or high-moisture lignites, a mechanical ignition zone is provided, consisting of a small compartment running across the entire width of the stoker and beginning at the point where the coal passes under the feed gate and first enters the combustion chamber. A suction is maintained here by which a small portion of the hot furnace gases is drawn down through and ignites the incoming green coal. The Illinois Natural-Draft Stoker is also provided with dampered air control, no air entering the combustion chamber except through the grate.

The Green Natural-Draft Chain Grate employs solid drive links with open filler links and oval bars. An adjustable fuel gate, lined with firebrick, hangs at the entrance, and a pressure water-back, connected to the boiler circulation, is employed at the rear of the grate. Immediately behind the first water-back is a water-cooled fuel retarder, which is hinged so that the ash-discharge opening can be varied from 1½ to 6 in. The water-back and retarder permit the building up of a compressed fuel bed without thin spots or air leakage at the ash-pit, and with the consumption of carbon from the tailings. A long flat arch is used, suspended from cast I-beams hung on steel frame work and set at such an angle as to receive and reflect the maximum of heat for fuel ignition and deliver the

operating at 150% of rating in 5 min. from the time it goes on the line, or it can be operating at 200% of rating in 7 min. With the ordinary short-banked fire, which consists of a bed of coal 3 to 4 ft. in from the stoker gate, the remainder of the grate being bare, the boiler can be brought up to 200% rating within 25 min., while with the long bank, in which 50% of the grate is covered with fire, the boiler can be brought up to 200% rating within 6 to 8 min.
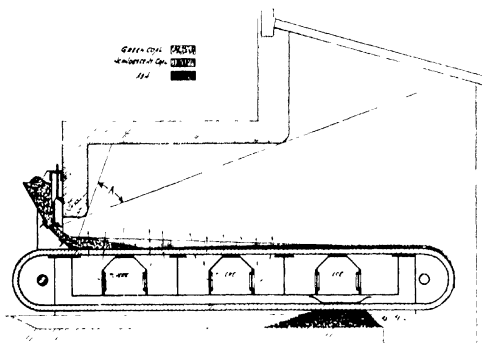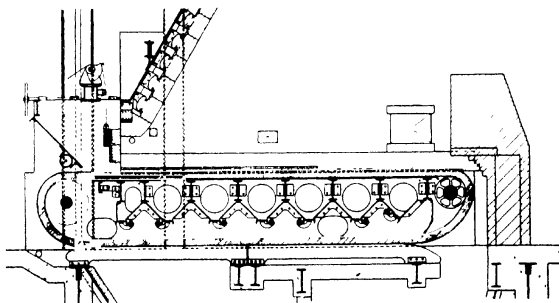
COXE CHAIN GRATE

ILLINOIS FORCED-DRAFT CHAIN GRATE

tact with flexible seals on the bottoms of the beams. The air pressure, which rarely exceeds 2 in. in any compartment, is usually carried highest in the second and third compartments from the front, over which ignition has been completed and the maximum rate of combustion takes place. An arch covering approximately 50% of the grate is recommended, 4 ft. above it, and sloping slightly upward toward the rear, with an ignition arch from 12 to 18 in long, approximately 21 in above the grate, immediately behind the stoker gate
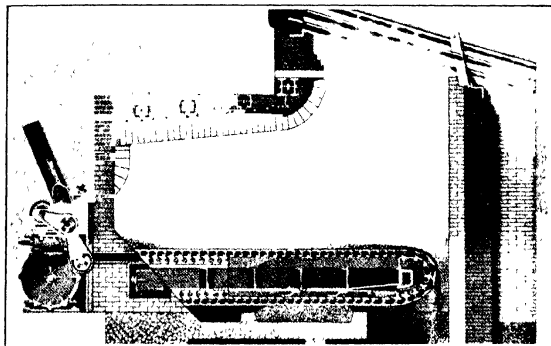
HARRINGTON STOKER

The Harrington Stoker has a grate surface made up of individual clips with interlocking edges, mounted on transverse racks The clips present a flat, non-sifting surface, the air outlets being maintained by the automatic removal of clinker as the clips separate at the rear end, where they roll on tracks cast on a box girder instead of on a shaft The fuel bed is undisturbed, from the delivery of green coal at the gate to the ash, which is discharged as formed at the rear of the stoker, and this permits the use of high-ash, low-fusion coal without excessive clinkering. The character of the bed changes with the progressive combustion, and the active grate surface is divided into four or more compartments, each compartment being supplied with low velocity air at varying pressure, through adequate dampers controlled from the front of the stoker. The stoker is used with coking bituminous, free-burning bituminous, lignite, all sizes and characters of anthracites, including river dredgings, coke breeze, wood chips, etc. It operates on natural draft up to 150% of nominal boiler rating, and on forced draft up to 300% or higher

The Playford Chain Grate has one large reservoir receiving air from ducts or directly connected blowers, with a system of shutter dampers controlling the air supply to individual portions of the grate. The adjustment is usually permanent, the rate of driving being controlled by changing the air admission pressure or the rate of chain travel. The grate consists of a double link chain, the part in contact with fuel being free to expand without affecting the adjustment of the lower or drive chain links.
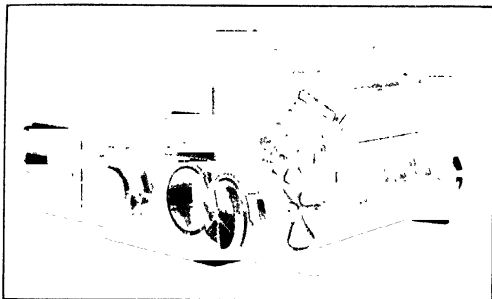
PLAYFORD CHAIN GRATE

The Stowe Conveyor Feed Stoker employs stationary sloping tuyere bars alternating with inclined moving chains, with a fuel-retarding assembly at the ash-discharge end The closely-massed fuel bed, of uniform, moderate depth, is subject to uniform wind-box pressure for its entire length. Air leakage is corrected by housing the conveying mechanism, leaving unhoused only that portion of the grate actually supporting the fuel bed. A damper system serves to reduce the effective grate area at light loads. When the coal is pushed onto the discharge plates, the moving layer becomes thicker, resulting in lessened air supply in the final stages of combustion. The stoker is used with all types of bituminous coals, including Eastern, giving high burning rates, high CO_2, complete combustion of gaseous fuels and low combustible content in the refuse. 300% boiler rating is secured with 2-in. air pressure.
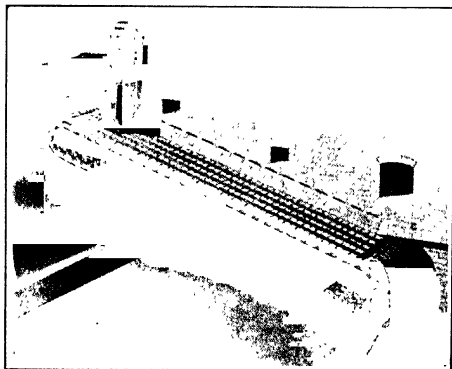
STOWE CONVEYOR-FEED STOKER

The Burke Traveling Grate has shaft and sprocket at the front end only, the chains rolling over a solid rear end. The grate bars, which are 1½ in. wide, are individually mounted on carriers driven by the endless chains, and are self-cleaning, as separation of adjoining edges of the grates in passage around front and rear ends breaks off any clinker. The drive chains are 6 in. below the fuel bed, and carry rollers spaced every 6 in., which roll on rigid steel tracks. The sprocket has five speeds, and a fuel-height indicator shows the position of the adjustable feed gate.
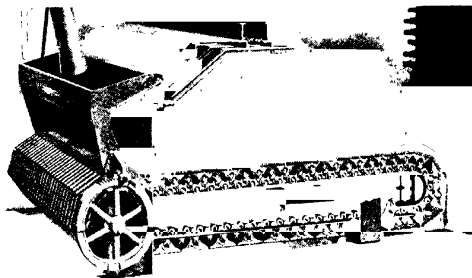
BURKE TRAVELING GRATE
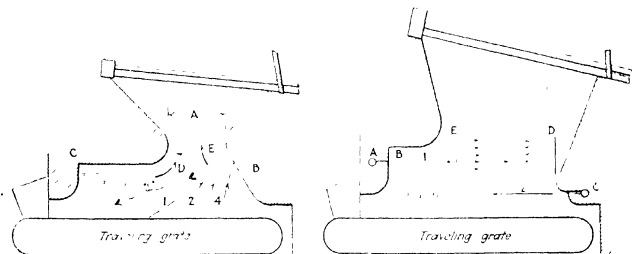
1 SETTING FOR LOW-GRADE FUEL   2 SETTING FOR HIGH GRADE FUEL
—Power.

C. M. Garland calls attention to the necessity of adapting chain grate settings to character of fuel. Fig. 1 shows a setting for exceptionally low-grade fuel with high moisture, with long ignition arch C and bridge wall B extending forward so that any radiant heat received by the boiler must go through the throat A, while heat radiated from the grate along lines 1, 2 and 4 is reflected back along 1, 2' and 4'. The distillation products shoot from below the arch C at a comparatively high velocity in the direction D and meet the oxygen-carrying gases E, breaking up stratification and resulting in combustion in the throat A, with subsequent

expansion and reduced velocity, preventing formation of slag on the
tubes. With high-grade fuel, the ignition arch can be short, as in Fig. 2,
and the throat large, the bridge wall C being extended front only far
enough to resist air inleakage, and 40% of the heat being absorbed by
radiation, giving increased capacity over Fig 1. The combustible gases
and oxygen will not be mixed, however, unless the boiler is 4 to 8 ft.
higher than in Fig. 1, or unless gas mixing streams are used He sug-
gests the discharge of about 2% of the total combustion products by front
and rear tuyeres 1 in in diameter and 18 in. apart, discharging along
lines 1 and 2; or, for large settings, the placing of rows of tuyeres verti-
cally on each side wall to discharge tangentially as at D and E He states
that mixing by air streams is less satisfactory, owing to the liability of
blow-torch action. While illustrated with water-tube boilers, Fig 2 is
adapted for bent-tube boilers, and Fig. 1 for horizontal water-tube boilers.

   H. S. Colby recommends the double-arch for forced-blast chain grates,
as illustrated in Fig. 4 for a horizontal vertically-baffled boiler set at a
moderate height, about 12 ft As will be seen from the lines showing
direction of heat propagation and reflection, with the single-arch furnace,
Fig. 3, the rear of the grate is unduly cooled by the boiler tubes. At the
front of the grate, hydrocarbons and moisture are distilled, and back of
this there is a CO section, through which it is impossible to deliver enough
air to burn the CO to CO_2 without retarding the ignition. Sufficient draft
can be carried in the central draft boxes, over which the fuel is ignited
clear through to the grate, to burn to CO_2 all the gas generated on that
section, and also to furnish some air for the CO from further front.
The air volume from the rear boxes should be just sufficient to support
the combustion of carbon in the ash residue covering these sections, but
there is usually a surplus of oxygen here With the wide throat of this
single-arch furnace, comparatively little diffusion takes place and it is
impossible to eliminate entirely a slight loss due to the presence of CO
close to the front wall With the mixing or double-arch furnace, it is
unnecessary to introduce so much air in the first and second zones to take
care of the combustible gases therefrom, hence ignition is more rapid, and
air for burning out combustible carbon and gases can be distributed over
compartments Nos. 3 and 4, and also at the rear The gases from the rear,
rich in oxygen, are diverted by the rear arch into the stream of rich
gases from the front, resulting in a mixing in the throat at high tempera-
ture.
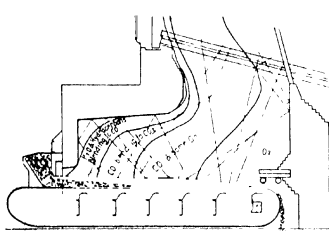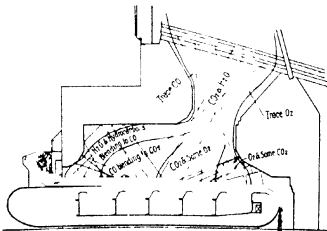
   3. SINGLE-ARCH FURNACE   4. DOUBLE ARCH FURNACE
                                              —*Steam Power.*

Roszak and *Veron* question the assumption often made that heat is reflected from an arch like light is from a mirror, that is, with equal angles of incidence and reflection. They state that brickwork acts more like a thermal pump approaching 100% in efficiency, the energy received from a given direction being liberated in all directions, with a maximum intensity along the normal to the surface. The reception of heat from the incandescent zone *I* of a chain grate, Fig. 5, would depend merely on the angle subtended by the points *A* and *B* with respect to *I*, regardless of the shape of the Arch *AB*, although the shape does determine the re-radiation from the arch to the front or gasification zone *G*. The arch in Fig. 5 is a good arrangement from the point of view of securing equal radiation to the entire ignition zone, but not for mixing the gases. It is adapted for coals high in volatile, requiring thorough gasification, especially if the arch is extended, to afford time for the gas to mix with air. The arch of Fig. 6, using two consecutive reflections, is adapted for poorer coals. *AB* can be vertical or horizontal, but is shown vertical for simplicity of construction. *BC* should be designed to afford a proper distribution of the radiated heat over the entire distillation zone *G*.

5. ARCH FOR HIGH-VOLATILE COAL   6. DOUBLE-REFLECTION ARCH

—Revue de Metalurgie
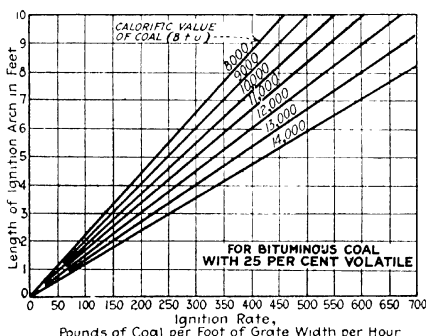
RELATION OF ARCH LENGTH TO IGNITION RATE ON CHAIN GRATES

T. A. Marsh says that the ability of a furnace to ignite coal depends upon the size of the arch and the ability to burn it when once ignited upon the draft, and presents the chart above as showing the relation of arch length to ignition rate on chain grates. For average conditions he recommends ignition arches set 15 in. above the grate in front and pitched 3 in. per foot of length.

W. M. Park describes the following chain grate settings as especially adaptable for Southwestern coals containing considerable clinker-forming ash. Fig. A represents a horizontal pass boiler with a chain grate, grate area and heating surface being in a ratio of 1 : 52. This arrangement readily ignites and burns 40 lb. per hr. per sq. ft., and has given 72% efficiency with New Mexico coal of 17% ash Fig. B shows a large combustion chamber used with a vertically baffled boiler, and a large opening between a high-set sloping arch and a vertical bridge wall. The entering fuel receives considerable heat by radiation, and the low gas velocity allows the burning of high-volatile but good grade New Mexico coals which would otherwise ruin the firebrick by the action of the gases. 15% CO_2 is secured. The semi-anthracites of Arkansas, with 60% carbon, can be burned in this setting. This fuel disintegrates like sand on heating, and ignites with difficulty, although this can be corrected to some extent by the use of a special gate having corrugated face tile in contact with the fuel. The furnace with the high steep arch shown in Fig. C is used for bituminous screenings mined near Fort Worth. Being of low heat content, they require a high grate ratio, say 1 . 25

Marsh describes the following chain grate settings as especially suitable for Illinois and Indiana coals, which require large grate surfaces. Large furnace volumes

A HORIZONTALLY BAFFLED
BOILER FOR HIGH VOLATILE
COAL

B VERTICALLY BAFFLED BOILER
FOR HIGH VOLATILE COAL.
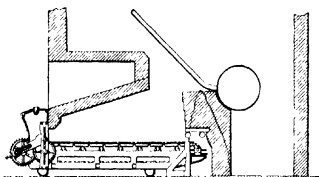
C SETTING FOR BITUMINOUS
SCREENINGS   —*Power.*

should also be provided, and long, high-pitched igniting arches Fig. D shows the application of this principle to a Stirling boiler, with an ignition arch over 80% of the length of the grate, a vertical bridge wall, and 12 cu. ft. furnace volume per sq. ft. of grate surface. Figs. E and F illustrate the difference between former and present practice. These represent an installation which was altered to permit of the use of a wider range of fuels, at high capacities. The arch was lengthened, and raised, except at the very front, resulting in more rapid distillation of volatile and better combustion of fixed carbon. Fig. G shows a furnace for a vertical boiler, which is well adapted to full dutch-oven furnaces. The size is larger than would be required merely for smokelessness, and is said to make it possible to burn clinkery, high-ash coal at efficiencies over 70%.

D   CHAIN GRATE FOR STIRLING
       BOILER
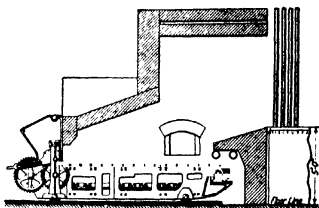
G   CHAIN GRATE SETTING FOR
         VERTICAL BOILER
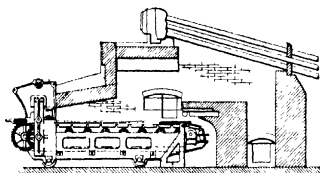
E   BEFORE

F   AFTER

CHAIN GRATE SETTING ALTERED TO HANDLE ILLINOIS COAL
—*Power.*
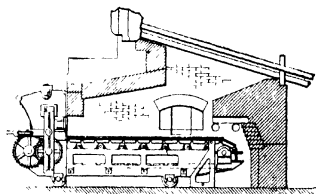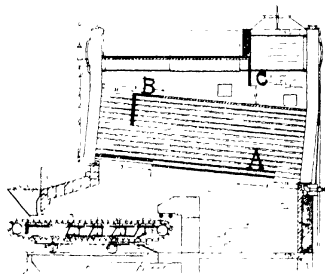
H   CHAIN GRATE WITH ZONE
       CONTROL —*Power Plant Engg*
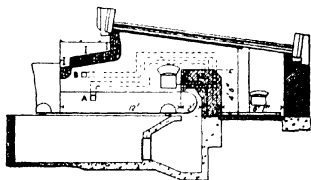
I   FOLTZ AIR DUCT SYSTEM
                                 —*Power.*

Fig. H shows a chain grate used in the North American Bldg., Chicago, and equipped with steel-plate boxes with sliding damper plates, dividing the grate into zones to which the air could be controlled or shut off entirely and making it possible to operate efficiently with reduced grate area at times of light load. Ashes collect on the flat top of the boxes and act as an air seal. The C-tile of the lower baffle was extended back at the point A, reducing the opening from 60 in. to 26 in., while at B the upper baffle was extended forward and a short vertical baffle dropped

from it, and baffle C was also placed below the drum just ahead of the
gas passage to the breeching. These changes reduced the flue-gas tem-
perature by 125°. 12% CO_2 is secured at all loads and 8 lb. actual evapora-
tion per lb. of No. 4 Southern Illinois coal. At 140% of rating the stack
temperature is 650° F. 230% rating can be carried with natural draft,
under normal load conditions the draft over the fire is 0.04 in and at the
damper 0.2 in. water.

Figure I shows a *Foltz* air-duct system applied to an existing chain-
grate installation which had caused excessive smoke From the inlets A
located in the side walls below the upper run of chain, the ducts rise up
into the furnace region, pass back, down through piers in the bridge wall
into the floor of the combustion chamber, where they proceed to the rear
end and double back, returning through the same side walls to deliver the
heated air over the fire from the outlets B. The preheating of the air
resulted in a hot fire back to the gate, reduced deposits on the tubes,
reduced the total refuse by 50%, and permitted the boiler to be operated
smokelessly up to 200% of boiler rating.
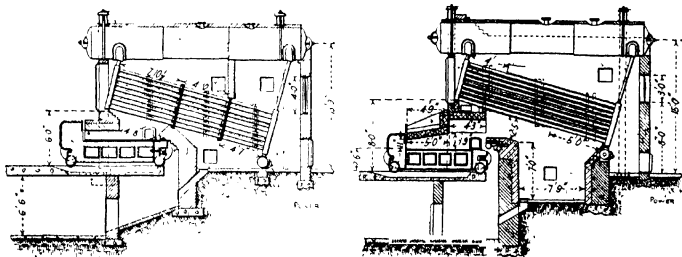
J. WATER TUBE BOILER REBAFFLED TO PREVENT SMOKE—*Power.*
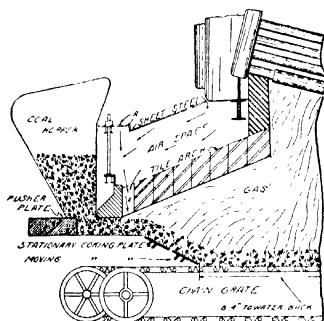
K. SMOKE PREVENTION WITH
CHAIN GRATE—*Power Plant Engg.*
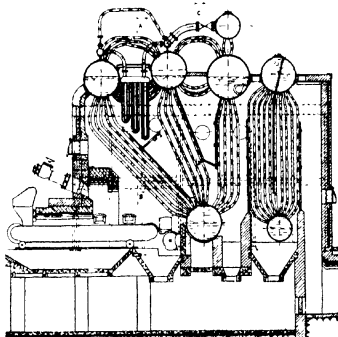
L. SPECIAL STIRLING BOILERS
AND CHAIN GRATE

The drawings, Fig. J, indicate changes made by *Osborn Monnett* in a 350 HP. vertically-baffled water-tube boiler which had given almost constant trouble from smoke. By raising the boiler two feet and inserting horizontal baffles to give a single pass, smoke was entirely eliminated, with a negligible drop in efficiency

The left-hand sketch, Figure K, by *C. B. Hudson*, shows an arrangement which is reported to have been successful in preventing smoke from a Green Chain Grate installation. Originally a mixture of bituminous slack from the Knoxdale plant of the Pittsburgh & Shawmut Coal Co. and anthracite screenings from the Northern Anthracite Co, Bernice, Pa., was burned, using about 1.2 lb. screenings to 1 lb. slack. The slack coked easily, and the particles of anthracite adhered to the coke, presenting a thick, impervious fuel bed. By stopping up all air leaks around the front of the furnace, a high CO_2 was produced Due to the exigencies of wartimes, it was necessary however to change over to all bituminous, and difficulty was at once found in getting a good CO_2 without making objectionable smoke. To remedy this, six 1½ in. holes were drilled through the ignition arch at the point X, where the gate tile and the arch come together, and the sheet steel cover plate A was removed This cut down the objectionable smoke by about 75%, and samples taken just over the tubes in the first pass showed CO_2 at times as high as 17.5%, with but little black smoke. Upon another boiler, the number of holes was increased to 13, with still better results, and CO_2 as high as 17 to 18% is at times obtained, readings of 15 to 17% being common. The introduction of secondary air at the point shown gives an excellent mixture and immediate combustion of the volatile distilled from the fresh coal. The breeching damper is controlled according to the indications of a duplex differential draft gage, showing the draft drop through the fuel bed and the draft drop through the boiler

Fig L, to right, shows a four-drum Stirling boiler with a superheater and economizer, designed by *B N. Broido*, with a chain-grate setting designed to burn coal or coke-oven gas, or both at peak loads. The boiler contains 3800 sq ft. heating surface, the superheater 650, and the economizer 1900 *Broido* states that a fire-brick arch over the furnace is an important feature in the setting of Stirling boilers, and that its design depends upon the kind of fuel used, and the capacity of the boilers In general, however, the grates should not be set flush, but should extend sufficiently to the front of the boiler to give a good ignition action. For a 4-drum boiler which will not be heavily overloaded, and for average good coal, an ignition arch about 5 ft. long gave good results The distance between the grate and the arch at the front was for the above conditions usually made 12 in, and a distance of about 20 in. was allowed at the end toward the boiler tubes, to provide more space for combustion. For carrying heavy overloads he advises that the grate should not be too short. On high loads the short grate will smoke badly on account of the thick coal bed, and a portion of the fuel will reach the end of the grate and fall into the ash-pit unburned. With the setting shown, tests upon coal of about 13,000 *BTU* per lb. gave furnace temperatures of 1880° with 8% CO_2, 2280° with 10% CO_2, 2675° with 12% CO_2, and 2860° with 14% CO_2. Due to the intense radiation from the large grate surface and the fire-brick arches, the first section of the boiler generated 60 to 80% of the entire quantity of steam.
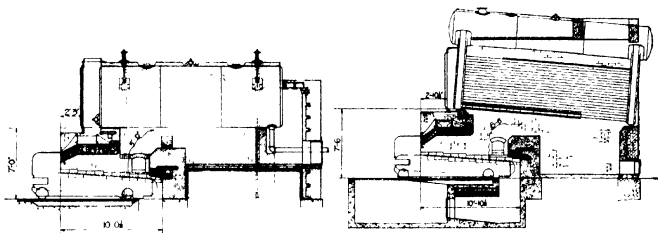
M. CHAIN GRATE SETTINGS FOR HIGH FURNACE TEMPERATURES
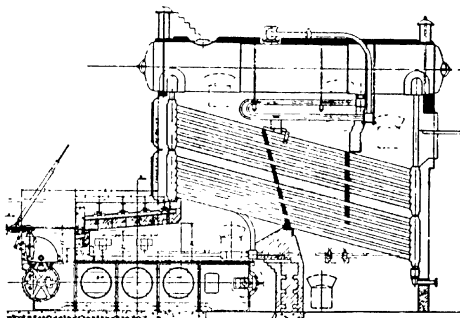
N. CHAIN GRATE WITH TURBO BLOWERS IN FURNACE—
Blast Furnace and Steel Plant
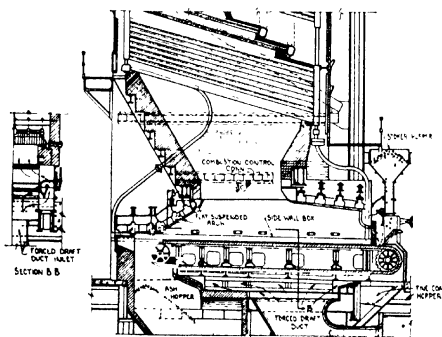
O. REVERSED ARCH CONSTRUCTION FOR MIXING GASES
—Power Plant Engg.

L. R. Stowe states that in the earliest chain-grate settings, without ignition devices, the fuel bed could not reach any higher temperature than that due to the combustion going on in it, the temperature being further kept down by radiation of heat to the black boiler tubes above the fire. Arches were then introduced over the feeding end, reflecting some of the radiant heat to the incoming fuel and causing quicker burning there, this method being very satisfactory with free-burning Southern Illinois coals. He gives the accompanying Fig M as typical of still later practice in deflecting the maximum amount of heat back into the fuel bed to increase fuel-bed temperatures

Fig. N shows a forced-draft chain-grate stoker which replaced a natural draft installation. The three circles in the stoker frame represent high-speed turbo-blowers which are used instead of costly fans and duct systems to supply to the furnace air under control

Fig O shows a reversed-arch construction used with chain grates burning Mid-Western fuels, for mixing the combustible gases with the incoming air
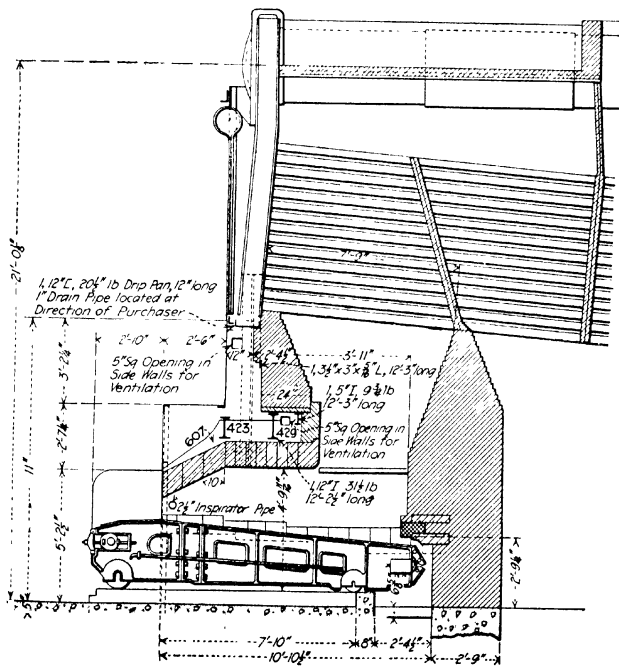
P. AN 11-FOOT SETTING FOR HIGH VOLATILE COAL.—*Power.*

Charles H. Bromley describes the chain grate setting for water-tube boilers illustrated in Fig. P as suitable for Middle Western high-volatile coals. The baffling is designed to give an approximately uniform gas velocity throughout the entire flame travel. The flame goes directly to the tubes from the incandescent zone, which is permissible on account of the high setting, 11 ft. above the floor. The arch and bridge wall give a fairly good mixing of air and combustible gases. The boiler setting illustrated in Fig. Q, from *Power*, is used by the *Cleveland Electric Illuminating Co.* The chain grates are located at what would ordinarily be considered the rear of the boilers, under the mud-drums, and separated therefrom by an ignition arch. The baffling is of the four-pass type, the gases entering the first bank of tubes at the top, and being carried off by a central flue after passing through the economizers.
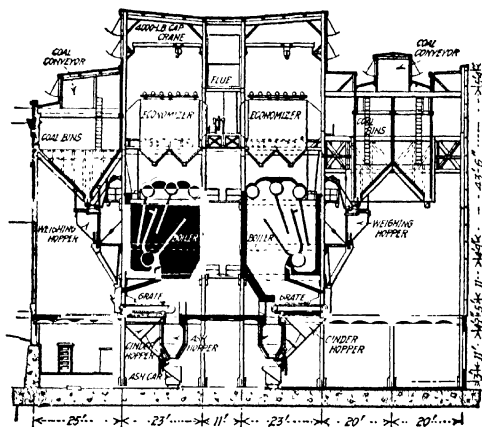
Q. STOKER SET UNDER MID-DRUM OF 4-PASS BOILER—*Power.*

Power describes the setting of the B. & W. Chain Grate, Fig. R, at the *Calumet Station,* Chicago. This is 24 ft. wide by 18 ft. 3 in. long, with an effective grate area of 410 sq. ft., boiler heating surface 15,089 sq. ft. The grate is driven from the front shaft, putting the top in compression and reducing siftings to the minimum, and water boxes are used at the side grate lines and at the back above the grate. Air enters through ten holes in the vertical leg of the ignition arch, cooling the latter and permitting smokeless consumption of the combustible gases. The main arch is 51 to 57 in. above the grate, giving 725 cu. ft. primary combustion space under it, and the total effective combustion space is 4856 cu. ft. When operating at 240% of rating, 35 lb. of 10,200 BTU Illinois coal was burned per sq. ft. grate per hr., and 75% efficiency obtained for boiler and furnace, or 81% including the economizer. The flue gases escaped to atmosphere at 320° F., and CO_2 was 13% at boiler uptake. There is a draft box on
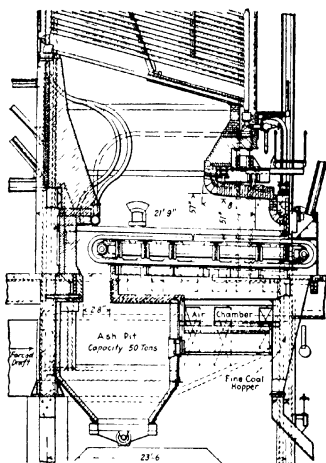
R. CALUMET FORCED-DRAFT
CHAIN GRATE INSTALLATION
—Power
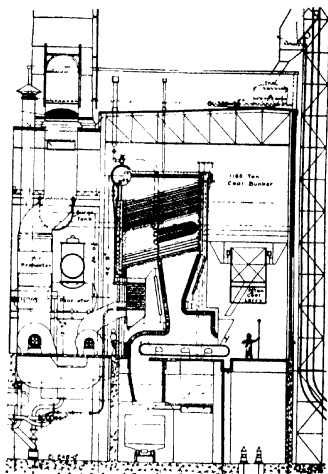
SETTING AT AMSTERDAM STATION
- Prime Movers Report.

each side, supplying air to the five individually-controlled compartments.
The auxiliary power required is 0 75%.

In the Amsterdam Station of the Adirondack Power and Light Corpora-
tion one vertical baffle extends both above and below the inter-deck super-
heater, resulting in a two-pass boiler. The Venturi furnace only flares suffi-
ciently to expose the first pass of the lower bank of tubes to radiant furnace
heat. Gases are discharged directly downward from the second pass of the
boiler to a steel tube economizer. The induced draft fan is located on the
boiler room floor in the bay behind the boiler. It draws the gases from the
economizer and discharges them downward into the flue. The flue makes a
return bend under the floor and up through the boiler room to the main
horizontal flue on the boiler room roof leading to the stack. An air pre-
heater is located in this vertical duct, which location is unique in being
on the discharge side of the induced draft fan.

Fig. S, from an article by *Thomas Wilson,* shows the layout of an
installation at *Fisk Street Station,* Chicago, consisting of a double chain
grate with total area of 330 sq. ft. under a 14,500 sq. ft. boiler of the
reversed type. The gases are drawn through an economizer over the
boiler by an induced-draft fan discharging to the smoke flue. The rate of
burning is about 43 lb. per sq. ft. of grate, but the large size permits
evaporation at the rate of 100,000 lb. per hr., or nearly 7 lb. per sq. ft.
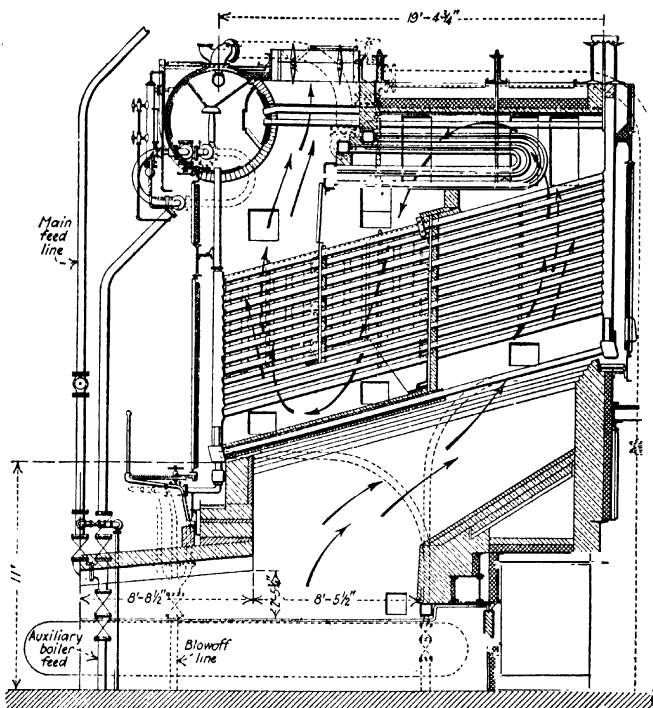
S. FISK ST. INDUCED-DRAFT CHAIN GRATE—*Power*

tube surface per hr., with an overall efficiency of 80% and above, using 1¼-in. Illinois screenings containing considerable duff. With a fuel bed 10 in. thick, an uptake draft of 2¼ in. and 0.6 in. over the fire was required, and air leakage occurred, even with steel casings. After careful gas sampling to locate leaks, they were closed by the use of fitted tile or other means, and the CO_2 at the inlet to the fan was increased to 10.5%, the temperature being less than 300° F. at this point.

Instructions for Chain Grate Operation.—Generally one operator and one coal-passer can handle about ten chain grate stokers. With chain grates either natural or forced draft can be used, although certain coals are not adapted to use forced draft successfully. Chain grates are usually large in area for the boiler, when compared with other types of stokers; the normal forcing capacity averaging 260% of boiler rating, with the

combustion rate up to 48 lb. per sq ft. per hr., with coal suitable for the stoker. With low ash coal, this rate of driving would probably cause the grate to become overheated, and high maintenance cost would result. To obtain best operating results, it is essential that the draft be under control, and that wide-open and tight-shut positions of the damper be determined and marked, and that dampers operate readily between these positions.

All gate leveling bolts can be adjusted to obtain a uniform fuel bed, but, before making this adjustment to correct an uneven fire, be sure that it is due to the gates and not to other causes. Some settings provide definite arch ventilation, and the openings through the side and curtain walls must be kept clear, and must indicate air circulation.

If the ledge plate flanges provided in some settings have been disturbed by the settling of the brick work, they should be set to within ⅛ in. of the stoker chain, to cut off air leaks between the chain and furnace wall.

For efficient operation, no unconsumed fuel should be carried over the end of the grate, and frequent gas analyses should be made. A few days' experimenting will determine the proper relation between fuel bed thickness and speed of grate. See that all air openings around the front of the stoker are effectually closed.

If the fire tends to draw away from the gate, decrease the speed, increase the thickness of the fuel, or adjust the dampers. The thickness of the fuel bed is shown on the gate indicator. Variation in gate height is necessary with coals varying in fineness and in volatile proportions. It is better to run a thick fire slowly than thin fires rapidly. The average speed should be about 3½ in. per minute. Keep the grate covered by closing the dampers and slowing down the stoker with decreasing load, and vice versa with increasing load. Keep the bottom side of the feed gate tile in line, as an uneven fuel bed makes an uneven fire. Insert new tiles when the old ones are burned or broken down. Dampers should not be entirely closed during operation. A furnace draft of 0 1 in. should be the lowest draft permitted.

If the fire tends to pass over into the ash-pit, the fuel feed is too fast or too thick, or the furnace is given insufficient draft. The fuel should be just consumed upon reaching the rear turning point. The back end of the grate should never become bare of live coals.

Adhesions usually form on the side walls. About once in six hours, run a bar under the hopper apron and gate, being careful not to dislodge the gate tile. This should be repeated regularly, as often as necessary to keep the side wall clean and prevent the side links from being burned.

Ashes should not be allowed to accumulate in a pile around the chain. This may tend to overheat it, and burn it out. Neither should the drippings of coal be allowed to accumulate. Put a little back into the hopper at a time, a large amount will act to make holes in the fire. It is not a bad plan to wet the drippings. Do not stop the stoker for any length of time with the hopper full of coal, as the fire will burn forward and injure the gate. Do not run short fires with the damper wide open, as high brick work deterioration and poor economy will result. Do not try to regulate the fire by opening the doors in the stoker setting. In washing out the boiler, be careful not to wet the stoker arch, as nothing is more injurious. Keep the arch dry. With a coking coal, it is necessary to run a slice bar through the fuel bed occasionally to break it up and permit free passage of air.

If run at proper speed, so that no unconsumed fuel runs over the end, the links at the stoker front can be touched with safety. The speed should be such that all volatile matter will have been driven off the coal by the time it has traveled not more than half the length of the grate. Varying loads can be easily taken care of by proper regulation of the thickness of the fuel bed and the speed of the grate. The damper will have to be regulated accordingly. Insufficient draft causes smoke in the stack and possibly in the feed hopper. If smoke is noticeable in the feed hopper, allow it to empty and inspect the gate shoes to determine whether they are overheated. If so, allow the hopper to remain empty until the shoes cool off.

To force the fire, open the boiler damper wide, speed up the grate, lower the feed gate, and loosen up the coal. A ¾-in. bar with a 6-in. bend at the end can be used. Run it through the furnace with the 6-in. leg flat on the grate. When at the rear, turn the bar completely over and pull it out. Continue until the whole grate has been gone over. Never disturb the top surface of the fuel bed.

To bank, allow the hopper to empty, stop the grate, partly close the damper, giving 0 1 in. draft in the furnace, until the fire burns short. Close the damper almost to the smoking point. Loosely bank the coal against the lower edge of the gate, allowing a little air to get through. At intervals of five hours run the grate ahead a little

To bring a banked fire up to rating, stir up the fuel bed with a bar, partly open the damper, lower the gate to the operative point, fill the hopper, and as soon as the arch is thoroughly heated, start the stoker at a rate that will keep the fuel ignited at the gate. When the grate is completely covered, the damper may be opened and normal operation begun.

C. E. Hayes calls attention to the fact that the value of wetting coal to be used on chain grates can be checked by uniformly wetting a pile of coal sufficient for two or three hours run, leveling the dry coal in the hopper, and placing this wet coal on top of it As the wet coal begins to travel along the grate, the improvement, if any, can be noted. For practical tempering, a 2-in. exhaust steam pipe can be placed in the hopper, 12 in. above the grate, and as near the front as possible, with a row of brass plugs 1 in apart, containing holes faced toward the boiler, 15° below the horizontal.

Thomas A. Marsh made tests on the effects of moistening coal before firing, but was not able to detect any splintering effect due to the formation of steam in the coal. To test the effect on air circulation, a 6-in. "bed" of Western screenings was placed on a screen in a vertical pipe, air was drawn through by a syphon, the draft measured by a gage and the velocity by an anemometer. It was found that for air moistened moderately the air flow was 50% greater than with dry coal, but if the coal was saturated, the air flow was less than with the "moist" coal. Tests were also made at constant draft, with the addition of weighed quantities of water, allowing 10 min. for absorption The chart shows that the maximum air flow occurred when 7.5% added moisture was present, and explains the higher combustion rates and increased boiler capacity obtainable with moist or properly tempered coal. The decrease in fuel bed resistance causes coal to burn to a cleaner ash by reducing the burning of holes in the fuel bed, and less coal sifts through unburned. Coal should
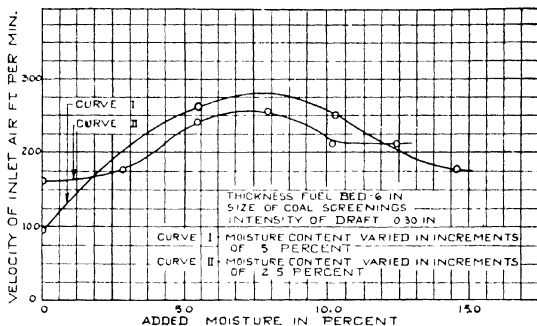
AIR FLOW THROUGH BED OF COLD FUEL AT VARYING MOISTURE AND
CONSTANT DRAFT —*Power Plant Engg.*

preferably be tempered in the crusher or conveyor, to give time for it to
mix, and exhaust steam can be used for the purpose

Jos. Harrington discusses the requirements for the burning of low-
grade, dirty coal, such as bone, cuttings, etc., containing large quantities
of ash. On a chain grate where there is no agitation, combustion at first
takes place most freely at the bottom, where the air supply is greatest, and
works to the surface. Further back, the air coming to the combustion
zone passes through the lower ash bed, keeping it cool and porous, and no
clinker is formed if the ash is kept out of the hot zone and is properly
discharged. High-ash fuel has such resistance that forced draft is required,
as mere thinning of the bed produces a leaky fire. As the volatiles and
carbons are burned out, the character of the bed and its resistance changes,
and graduated areas of different draft intensity should be maintained. The
grate surface must also be non-porous, so that fine material will not sift
through, allowing hot particles from above to strike and injure the grate,
and open up air holes in the fire.

OVERFEED STOKERS

In most types of overfeed stokers, coal is pushed in at the top of a
sloping grate and coked by the aid of a fire-brick arch. The coal is moved
from the top to the bottom of the grate by various motions of the bars,
aided by gravity. Clinker collects at the bottom, and is crushed or dumped
according to the design of the stoker. Coking is confined to the top of
the furnace. The packing of the green coal makes it impossible for air to
get through under slight differences of pressure, and air for burning the
volatile is supplied from openings in the arch, or from excess air admitted
through the lower part of the grate.

Geo. I. Bouton gives the following points in connection with over-
feed stokers. The side-feed double-inclined or V-type stoker has two
grates each with 45° slope, meeting at the center and presenting a V-
shaped section when viewed from the front. Flush-front settings can be

used with smaller return-tubular boilers and horizontally-baffled water-tube boilers, but with other boilers a Dutch-oven should be built in front of the boiler The grate surface varies from 4 ft. wide x 3 ft. deep to 12 ft x 9 ft., with 1 sq. ft. projected grate area per 6¼ rated boiler HP. for large stokers, and 1 sq ft. per 5 rated HP. for small stokers The boiler should be set sufficiently high so that the front header or the sill of the tube-door opening clears the top of the arch about 3 in, meaning a height of about 6 ft. on a 100 HP. boiler, 7 ft. 9 in. to 8 ft. 3 in. on a 300 HP. boiler, and 11 ft. 3 in. on a 600 HP. boiler Vertical water-tube boilers should have a combustion space of somewhat greater cross-section than that of the stoker, with the distance from the rear end of the grate surface to the tube surface 6 or 7 ft. The stoker is preferably driven by a small engine, the steam from which can be used to chill clinker on the grinder and the lower ends of the grates, although a motor can be used

It is desirable that the fuel be fed as uniformly as possible to the stoker. The fuel bed is about 8 to 10 in. thick at the upper end of the grates, thinning down gradually toward the clinker grinder Minor fluctuations in load should be taken care of by minor variations in the draft over the fire Where the load changes into a decidedly higher or lower range, the coal feed should be increased or diminished to meet this range, the draft over the fire being regulated to take care of the immediate needs of the boiler.

The draft loss through the fuel bed will vary with the amount and kind of coal being burned, the high-volatile coals requiring less draft than the lower-volatile coals The amount of draft required is also affected by the amount and kind of ash which the coal carries Where proper draft is provided, stokers of this class will take care of varying loads readily up to 200 or 225% of boiler rating, although the draft available usually limits the capacity to 200% of boiler rating or less Where there is a shortage of draft it is possible to compensate for this in part by increasing the amount of "rousting" or hand manipulation of the fuel bed. At 200% of boiler rating the draft loss through the fuel bed will vary from 0.3 to 0.5 in. water gage, depending on the kind of coal and the amount of rousting. Additional capacity can often be obtained by adding forced draft, the air being admitted to the space beneath the grates, either at the front or rear, in a line parallel with the clinker grinder; two inlets being used, placed symmetrically with reference to the stoker center line. The amount of air reaching the furnace through the openings in the arch plates should increase with the capacity, as occurs with natural-draft conditions. The limit of forced-draft capacity is when the draft over the fire is reduced to 0.05 or 0.10 in, so that fire is blown out of various openings It is possible under favorable conditions to get in the neighborhood of 300% boiler rating, although it requires close attention on account of the thin fuel bed. With natural draft, the damper at the boiler outlet is controlled by hand or by a regulator actuated by varying steam pressure.

Among the front-overfeed single-inclined stokers, the Roney is made up of a 35° inclined grate with transverse bars, with sectional grate-bar tops giving uniform air distribution Flat coking plates are provided at the upper end and a rotary motion of the transverse bars feeds the fuel to the lower end, where there is an agitator for breaking up and damming back the clinker, with slotted dump grates, admitting air to complete combustion. The engine is driven at constant speed, but variable feed is secured by adjusting the stroke of the pusher and grates. The fuel-bed thickness

is uniform for a given coal, the damper controlling the boiler rating. The stoker is used with natural draft, with anthracite, bituminous coal, lignite, hogged fuel, etc., and is set with an ignition arch. The Wetzel stoker has a grate made up of a series of ribbed bars extending from front to rear, the upper end having a slight forward-and-back motion, and the lower end a motion at right angles to the grate surface.
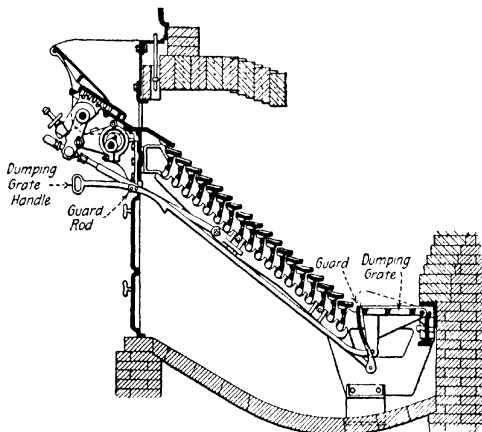
WESTINGHOUSE RONEY OVERFEED STOKER

The Westinghouse-Roney Stoker.—A reciprocating action of the lower plate on the front of the hopper causes the coal to slide onto the coke plate underneath an arch, which assists in the ignition. The grate bars are transverse, and rock backward and forward. Natural draft is used. For cleaning the fire, a guard is lifted into position between the dumping grate and the regular grate bars. This should break the clinker free from the grate. The ashes are dumped by tilting the dumping grates. This stoker is used for both high volatile Western coals and high fixed carbon Eastern coals.

The Murphy Furnace is a V-shaped side overfeed stoker, with coal magazines running along each side from front to back. Below these are the coking plates, cooled by air ducts under them, and with stoker boxes above them, moving back and forth and pushing the coal through the throat openings onto the grates. The grates are alternately fixed and movable, and slope down to the horizontal clinker grinder, which is parallel to the magazines. The movable grates are pivoted at the top, and oscillate above and below the surface of the stationary grates. An arch plate forms the inner wall of the magazine and has numerous ribs cast on it, forming a series of air ducts immediately above the coking plate, which deliver the heated air from the hot air chamber in small jets under the furnace

used with smaller return-tubular boilers and horizontally-baffled water-tube boilers, but with other boilers a Dutch-oven should be built in front of the boiler The grate surface varies from 4 ft. wide x 3 ft. deep to 12 ft x 9 ft., with 1 sq. ft. projected grate area per 6¼ rated boiler HP. for large stokers, and 1 sq ft. per 5 rated HP. for small stokers The boiler should be set sufficiently high so that the front header or the sill of the tube-door opening clears the top of the arch about 3 in , meaning a height of about 6 ft. on a 100 HP. boiler, 7 ft. 9 in. to 8 ft. 3 in. on a 300 HP. boiler, and 11 ft. 3 in. on a 600 HP. boiler Vertical water-tube boilers should have a combustion space of somewhat greater cross-section than that of the stoker, with the distance from the rear end of the grate surface to the tube surface 6 or 7 ft. The stoker is preferably driven by a small engine, the steam from which can be used to chill clinker on the grinder and the lower ends of the grates, although a motor can be used

It is desirable that the fuel be fed as uniformly as possible to the stoker. The fuel bed is about 8 to 10 in. thick at the upper end of the grates, thinning down gradually toward the clinker grinder Minor fluctuations in load should be taken care of by minor variations in the draft over the fire Where the load changes into a decidedly higher or lower range, the coal feed should be increased or diminished to meet this range, the draft over the fire being regulated to take care of the immediate needs of the boiler.

The draft loss through the fuel bed will vary with the amount and kind of coal being burned, the high-volatile coals requiring less draft than the lower-volatile coals The amount of draft required is also affected by the amount and kind of ash which the coal carries Where proper draft is provided, stokers of this class will take care of varying loads readily up to 200 or 225% of boiler rating, although the draft available usually limits the capacity to 200% of boiler rating or less Where there is a shortage of draft it is possible to compensate for this in part by increasing the amount of "rousting" or hand manipulation of the fuel bed. At 200% of boiler rating the draft loss through the fuel bed will vary from 0.3 to 0.5 in. water gage, depending on the kind of coal and the amount of rousting. Additional capacity can often be obtained by adding forced draft, the air being admitted to the space beneath the grates, either at the front or rear, in a line parallel with the clinker grinder; two inlets being used, placed symmetrically with reference to the stoker center line. The amount of air reaching the furnace through the openings in the arch plates should increase with the capacity, as occurs with natural-draft conditions. The limit of forced-draft capacity is when the draft over the fire is reduced to 0.05 or 0.10 in , so that fire is blown out of various openings It is possible under favorable conditions to get in the neighborhood of 300% boiler rating, although it requires close attention on account of the thin fuel bed. With natural draft, the damper at the boiler outlet is controlled by hand or by a regulator actuated by varying steam pressure.

Among the front-overfeed single-inclined stokers, the Roney is made up of a 35° inclined grate with transverse bars, with sectional grate-bar tops giving uniform air distribution Flat coking plates are provided at the upper end and a rotary motion of the transverse bars feeds the fuel to the lower end, where there is an agitator for breaking up and damming back the clinker, with slotted dump grates, admitting air to complete combustion. The engine is driven at constant speed, but variable feed is secured by adjusting the stroke of the pusher and grates. The fuel-bed thickness

The Reagan Stoker is an overfeed power operated stoker with bars set at an angle of 40° and in motion in opposing directions. Air is supplied to the fuel bed by forced draft, being uniformly distributed by the air ducts. Coal is fed onto the grate bars from a hopper automatically and, due to the motion of the bars, gradually works down to the horizontal extension grate. The ash falls over the water-cooled extension grate to the receptacle from which the coolest portion is drawn forward periodically by the ash pusher.
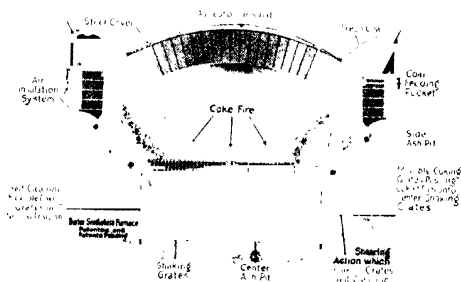
BURKE SMOKELESS FURNACE

The Burke Smokeless Furnace is intended for boilers up to 275 HP. The coal is fed from both sides behind a bed of incandescent coke, and is slowly ignited as it works down to the shaking grates over self-cleaning movable coking grates. In the gravity-feed type the coking grates, which form the incline between the side-wall and the bottom grates, are stationary. In either type the entire grate surface, which slopes down slightly to the rear, is covered with a fire-brick arch which conducts the gases back to the boiler passes.

The King Stoker has been designed by Jos. Harrington for use in furnaces from 3 sq. ft. of grate up to 250 HP. The grates are terraced or stepped, the first and third sliding back and forth over the second and fourth, so that the fuel bed is disturbed only by its fall over the ends of the grate bars. The coal is fed from the hopper over a reciprocating plate having an adjustable travel up to 5 in, which leads it to the grates, from which it falls to an ash plate with a reciprocating motion which slowly moves it front to the sealed ash door.
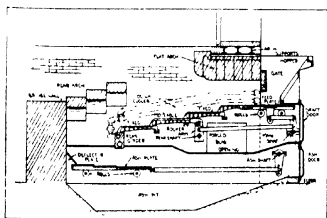
KING STOKER—*Power Plant Engg.*

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Stoker is built on a similar design, the fuel being distributed over the sloping surface without the use of hoe or slice bar and without opening the fire doors, while in the full Mechanically-Operated type the coal push-ers and stoker bars are operated by independent hydromotors supplied from a steam-controlled pressure system   Both semi-mechanical and full-mechanical types can be operated with natural draft, forced draft being used for overloads up to 250% of rating.

The McClave Hopper-Feed Hand Stoker for anthracite has large hoppers receiving coal from overhead bunkers or from lorries, industrial trucks, etc. Every 10 to 15 min. the gate C is opened by the lever D, dropping coal to the dead plate F, when furnace gate A is opened by the weighted lever B, and the fuel pushed in with a hoe   Dead or burned spots are re-coaled as desired. Each grate bar G is pivoted at its center, so that the ash can be dumped in sections   Buckwheat, barley, pea, screen-ings, culm, birdseye and dust are burnt, with four different types of grates, the air space ranging from 7 to 32%, and the mesh from $\frac{5}{64}$ up to $\frac{1}{4}$ in. Shaking grates are also furnished without the hopper feed.   A similar stoker for bituminous coal has a coking plate under the gate, a hollow arch for preheating air, and grates in which groups of "kickers" can be swung up to the position shown dotted, the curved backs serving to pre-vent sifting.   Cut-out bars and clinker shear plates are used for the removal of ash

Row of Pushers
in firing position

Dead Plate

Stationary
Grate Bars

Row of Pushers raised

Dump Plate closed

Dump Plate
Bracket

Hook for
Dump Rod

Pusher Rod

Dump Plate
Arm

Dump Rod   Ash Pit Door

Bearing Bar

Dump Plate open
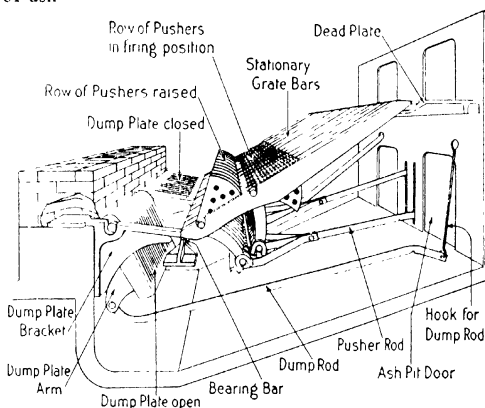
NATIONAL STOKER

The National Stoker is a hand-operated inclined grate designed for plants up to 500 HP. Coal is placed in heavy charges on the dead plate, and when it has been coked by the heat radiated from the ignition arch, it is pushed by the new charge down the stationary grate bars, which form a complete surface, except for herringbone air openings, at the top, but further down consist of middle ribs with lateral fingers. Two or three rows of sector-shaped pushers, interspersed between the bars, serve to

move the coke along the bars to the pivoted dump plate. Each row is operated independently, by a lever in the front of the furnace, as is also the dump plate
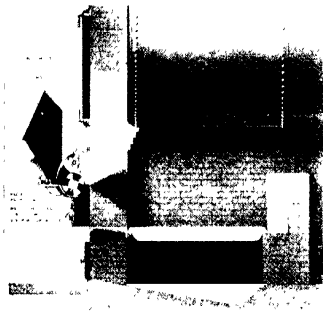
The Dayton Fuel Feeder

is designed for use in smaller plants or in locations where space is limited The fuel drops in front of the pusher box by gravity from the fuel hopper and is delivered to the distributing blades by the pusher box, while the revolving distributing blades throw the coal onto the grate surface The blade speed is permanent for a given installation, but the pusher speed is adjustable. Two feeders can be used on wide boilers, and less than 1 HP is required per boiler, which can be furnished by small engine or motor

DAYTON FUEL FEEDER

C H Ridderstedt has devised an agitating grate for burning solid fuel in suspension The cam B serves to raise and lower the grate, which is hinged at D, while the bolt E fixes the general slope of the grate and hence the rate at which the fuel and ash move to the left Air is supplied through F, which has flexible connections to the air-box G The bouncing of the fuel facilitates the access of air to each particle, and prevents the accumulation of clinker or the formation of air holes
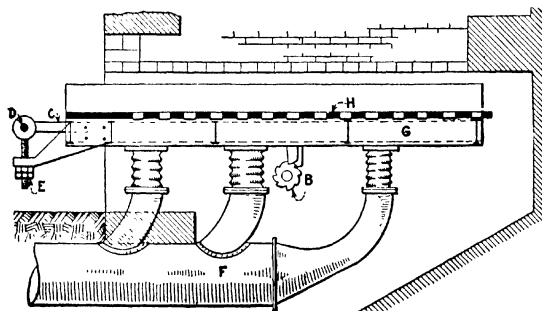
AGITATING GRATE —*Power*

S. W. Flagg reports a case where a coal of high ash content was found desirable for use on an overfeed stoker. The grate surface was made of hollow bars of 4 in. width, the removable tops of which formed a stepped
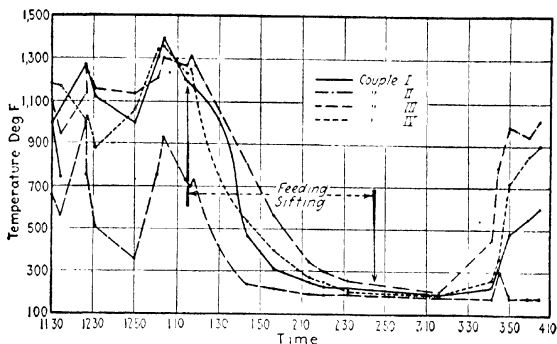
TEMPERATURES AT SURFACE OF STOKER BARS—*Power*

surface with the air openings in the vertical faces. Alternate bars were given an adjustable horizontal reciprocating motion. A high-grade West Virginia bituminous coal of 4 30% ash was tried, but gave so much trouble from burning of grate bars that the expense of stoker maintenance became prohibitive, and it was difficult to keep a sufficient number of boilers in operation. In order to investigate this, four thermocuples were embedded in different points ⅛ in. below the fuel-bearing faces, the observed temperatures being as shown in the chart, in which the hour from 11.30 to 12.30 is to a more condensed scale than the rest. At one o'clock the steam jets under the grates were shut off, as was often done by the regulator or by the firemen cutting off the air supply except that from natural draft, and the temperature rose so rapidly that the jets had to be turned on again. Later a collection of siftings of coal and ashes from under the grate was mixed with the feed, so as to increase the ash content without changing the character of the inert material, which had a softening temperature of 2224° to 2448° F. The protective influence of the increased ash was so evident that higher-ash coal was selected for future use on the grates.

   Operation of Overfeed Stokers.—Trouble may arise from fusion of ashes in contact with the side walls and bridge walls Excessive clinkering can be prevented by slicing the fires and dumping the ashes before they fuse If dumping periods are infrequent, the fuel will be all consumed. If dumping is done at too short intervals, the combustible is not all burned. The fireman can determine the length of time between dumpings.

   Keep the grates covered with fuel, the thickness depending upon the load. The inrush of cold air through an uneven fuel bed will decrease the efficiency, and it can be prevented by regulating the fuel feed.

UNDERFEED STOKERS

   H. F. Lawrence discusses the design and operation of underfeed stokers, which he defines as stokers in which coal is fed from beneath the burning fuel, through retorts with adjustments so that the fuel bed is replenished throughout the length of the retort. The main feed from hopper is by rams of fixed displacement, so that ram speed fixes amount

fed per hour. The original single-retort stoker consists of a horizontal retort, into which fuel is fed from the hopper and distributed throughout the length of the retort, with air-supplying tuyeres around the edge and dead or dump plates on each side, and, in wider furnaces, inclined movable grates or tuyeres between the retorts and dump plates, providing more grate surface and depositing ash on the dump plate. Such stokers have shallow ash pits, the ash being withdrawn from pits or dead plates through doors in boiler front, so that little excavation is required for installation and boilers can be arranged in batteries, as no side doors are required. The multiple-retort stoker consists of a number of single retorts placed close together and inclined with the ash discharge at the rear. The ash forms on top of the fuel bed and is floated to the rear and deposited on dump plates or in deep crusher pits from which it is continuously removed by rotary toothed crushers while the last of the combustible burns out. The secondary coal feed, from retort to fuel bed, is obtained in the Taylor stoker by additional rams, reciprocating horizontally in the bottom of the retort. The Westinghouse and Frederick have a lesser inclination and the secondary feed is by large wedge-shaped castings reciprocated on an inclination corresponding to the slope of the bottom of the retort. The Jones and Detroit have similarly shaped retorts, with secondary feed by small wedge-shaped pushers reciprocated horizontally, while in the Riley the retort sides and tuyeres are reciprocated. The tuyere angle varies from horizontal in the Detroit to 25° in the Taylor. The Lateral-Retort stoker feeds coal through a main retort extending from front wall to bridge wall, with lateral retorts branching at right angles, and can be installed under low-set boilers and without basement. All multiple retort stokers are for forced draft and cannot be operated at any appreciable capacity with natural draft. The combustion air circulates beneath and cools the furnace parts, and tuyeres placed between the retorts serve to convert the static head of air into velocity and direct the air flow through the fuel fed.

The incandescent burning fuel is on top and is replenished throughout the entire retort length from beneath. As the coal emerges from the retort it is coked and spreads over the tuyeres, forming a homogeneous fuel bed across the entire furnace width. As the fuel approaches the surface the volatile matter is completely distilled off and the fuel completely coked. The surface consists of a layer of incandescent burning coke. The air for combustion is introduced near the point where the fuel emerges from the retort. As the volatile gases are liberated they are thoroughly mixed with air. As the mixture passes up through the fuel bed, higher temperature zones are reached and complete combustion of the volatile gases takes place when they pass through the white-hot coke at the surface. Smokeless combustion is obtained without the use of special mixing or ignition arches or special brickwork construction. As the fuel bed is replenished from beneath the surface, the burning incandescent coke which is on top is slowly moved toward the dump plates. As the ash is formed it is floated on the surface and is eventually deposited on the dump plates. The control of the fuel bed is obtained by adjustments of the secondary coal-feeding arrangement. For good operation it is essential that the fuel bed be so controlled that the replenishing coal emerges from the retort through its entire length; the lesser amount being fed from the rear end of the retort. With low-grade Western coals more fuel must be discharged from the rear end of the retort than with the high-grade Eastern fuels. In general, the greater the quantity of ash in the coal, the longer should be the stroke of the secondary fuel-feeding mechanism.

If insufficient coal is fed from the lower or rear end of the retort, the ash, instead of being carried on to the dump plates, is deposited at the lower end of the retorts, and as high fuel-bed temperatures are always obtained the ash is clinkered, and when deposited at this point it blocks the air discharge. After a short interval, fuel from the upper part of the retort, which is not coked, is deposited over this clinker formation and then avalanches on to the dump plates. With this condition of fuel bed it is impossible to secure good results or good operation. With proper strokes of the secondary coal-feeding mechanism this condition can be eliminated, as with the proper amount of coal being fed from this section of the retort the ash and clinker can never be deposited at this point. This is really the important adjustment to be made for various grades of coal, and it probably receives less attention from plant operators than any other variable. When properly adjusted the fuel bed is automatically maintained clean, and high rates of combustion can be obtained

With the underfeed stoker properly adjusted, fresh fuel will be fed up throughout the length of the retort. Green fuel moving upward with respect to the tuyeres tends to keep them buried, and consequently the ironwork is in the comparatively cool zone of the fuel bed. For this reason the maintenance is low on underfeed stokers

With the underfeed system of combustion the excess air required can be reduced to a minimum, which means that high fuel-bed temperatures are obtained. The fuel-bed temperature will probably always exceed the ash-fusion point of any of our coals This means that clinker must be formed in order to secure the best combustion results These stokers are particularly adapted for burning bituminous and semi-bituminous coals. However, with only slight modifications lignites and coke breezes are also burned with excellent results

With the thoroughly coked thick fuel beds carried, this apparatus is very quick in responding to load demands Under running conditions the boiler capacity is quickly doubled, while 200% boiler rating is reached from banked fire in a few minutes. To prevent clinker adhesion to side walls, use is made of high side tuyeres or of perforated firebrick blocks located along the clinker line, through which air is blown from the stoker air duct, taking care to discharge no free air above the fuel bed. Cast-iron side-wall air boxes are also used, the faces toward the fuel bed being made of small overlapping ribbed plates, or carborundum bricks can be used if the ash does not contain much iron

The small figure shows the progress of coal through an underfeed stoker equipped with distributing rams over the entire bottom, driven from the main feeding ram The distance between parallel lines, indicating movement for each stroke, has been exaggerated for clearness.

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of side-wall air plates, air-cooled crusher plates, water-backs, rotary ash discharges, etc., all to keep the ash from halting in its course down the bed or on an ash-storage plate.

The *Riley Underfeed Stoker* is an inclined multiple-retort stoker in which the retort sides are reciprocating and carry grate blocks which bridge the spaces between the retorts, with side tuyere openings in them for allowing air to enter the green fuel below the zone of combustion. Coal enters the hopper by gravity and is fed into the retorts by a plunger, while the motion of the retort sides distributes it and keeps the bed open, porous and free from clinkers. The high moving side tuyeres prevent side-wall clinker trouble. Coke gradually works down to the reciprocating overfeed grates, which extend the entire width of the furnace and which permit the partially-burned coke, from which volatile has been distilled, to come into intimate contact with air at a pressure lower than that in the underfeed section. Beyond these are the power-operated rocker plates, which by a combination of horizontal and vertical rocking motion continuously agitate, crush and eject the ash. The opening between the rocker plates and the bridge wall is adjustable and disposes automatically of a large part of the refuse, so that cleaning and dumping periods are less frequent than with stationary dump arrangements. At low rating, natural draft can be used by removing the plates from front of furnace. The angle of incline is 20°, except with the Super-stoker, for very heavy duty, where it is 15°. In the latter the underfeed section has two air zones so that the pressure at lower end of retort can be lowered, and the retort sides are tapered, so that the coal moves upward as well as forward from the retort and spills sidewise over the grates. Single or double-roll clinker grinders can be applied.
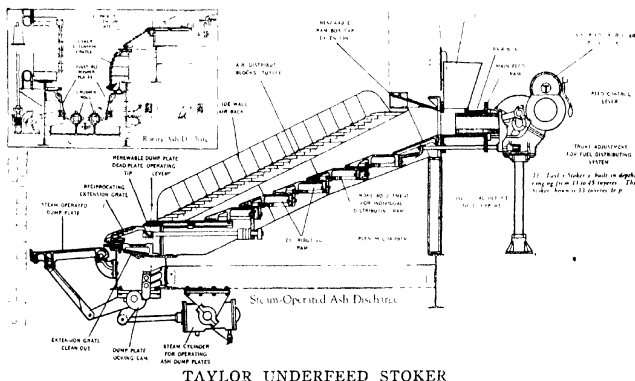
TAYLOR UNDERFEED STOKER

The *Taylor Underfeed Stoker* carries the fuel bed on an inclined structure made up of a series of narrow sloping passages at right angles to the front of the furnace, known as retorts, alternating with inclined stacks of air-supply blocks or tuyeres. Coal from the hopper falls into

ram boxes, from which the main feeding ram forces it into the retort. After this ram has covered about two-thirds of its stroke, it moves in unison with the distributing rams under the retort, and the sloping faces of the latter also raise and push the fuel forward, so that when they are withdrawn space is left for the next charge of green fuel. The entire fuel bed is thus underlaid with green fuel which is pushed up, step by step, into the coking zone, where it is gradually coked by the heat from the fire above, releasing its volatile gases, then into the combustion zone where it forms the bed of incandescent coke and is consumed to ashes, being carried to the ash-discharge system by the action of gravity and of the distributing mechanism The slicing action of the rams keeps the bed open without causing sufficient agitation to favor clinker formation. Low-pressure air is admitted to the rear of the plenum chamber under the retorts and enters the furnace through the tuyere openings which direct high-velocity streams into every part of the incandescent coke. Combustion is regulated by adjusting permanently the speed of each ram to the character of the fuel, keeping the air pressure the same everywhere in the retorts. A reciprocating extension grate supplied with low pressure air controlled from the side of the setting serves to burn out any carbon remaining in the refuse, which is removed either by a hinged steam-operated ash dump or by a rotary ash discharge, sometimes called a clinker grinder.

   The Westinghouse Underfeed Stoker is an inclined multiple-retort stoker, with the motion of the secondary rams *S* forming the beds of the retorts counter to that of the main feeding ram *R*. This agitates the fuel bed as the rams approach and recede from one another, uniformly distributing the fuel At the foot of the retorts is an extension agitating grate *G*, driven by a steam or air cylinder, controlled by a pilot valve mounted adjacent to the side furnace door. A large windbox with rec-
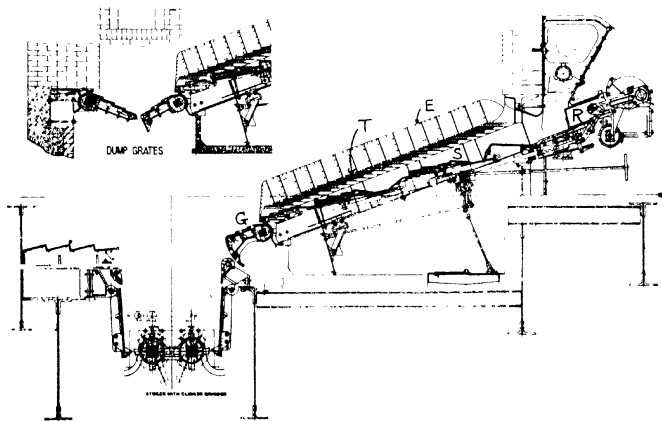
WESTINGHOUSE UNDERFEED STOKER

tangular dampers is located beneath the stoker, and supplies air to the air distributing box, which forms the top tuyere and has jets directed away from the front wall, to the regular tuyeres T lying between the retorts, and to the extension side-wall tuveres E. Air circulation maintained by the wind-box pressure over the corrugated interior surface of the latter, reduces their temperature and minimizes ash adhesions to the side walls. The double dump grates are supplied with air from the wind-box and are operated by steam or air cylinders; or clinker grinders with chamber walls which are practically vertical, assure positive discharge of the refuse into the deep pit, where the large rolls dispose of it.
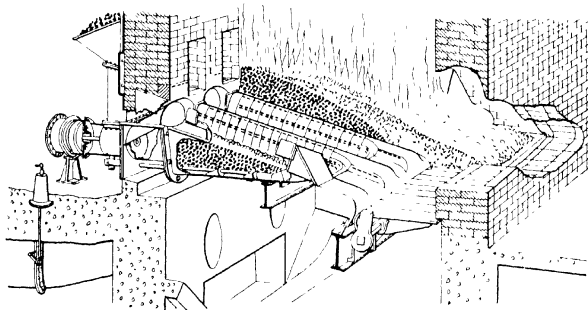
JONES A C UNDERFEED STOKER (Side View)

The Jones Automatic-Cleaning (A-C) Underfeed Stoker is a multiple-retort stoker in which the retorts are long and deep but nearly horizontal. A ram is connected to the steam cylinder in front of each retort, and when it is drawn outward a charge of coal falls into the ram case and is then forced into the retort, a rod carrying two pusher blocks extending below the ram through the front end of the retort. No moving part is exposed to the fire and the only movement is the straight quick thrust of the ram and pusher blocks buried deep under green coal. Non-sifting tuyere plates located between the retorts admit air from the wind-box, while the air-cooled side tuyeres project 6 in from each side wall and extend one foot above the level of the center blocks. Each particle of coal and all the gas pass through the incandescent zone, and the upward and rearward travel causes an automatic slicing and mixing of air and gases. The slight slope prevents avalanching, and there is little burning of fuel on the dump plate, which is dropped periodically to the sealed ash pit by hand or compound levers. Every grade of coal is handled, high-grade bituminous, free-burning Mid-Western, lignites, and mixtures of soft coal with coke breeze and anthracite. The Jones Standard Underfeed Stoker is a single-retort stoker with feeding arrangement similar to the A-C, but with a hand-cleaned dead plate for refuse. It is operated with bituminous coal, from bone and screenings up to Pocahontas, also in connection with Dutch ovens where refuse is introduced from above and coal is fed from the hopper when needed. The Jones Standard Side-Dump Stoker
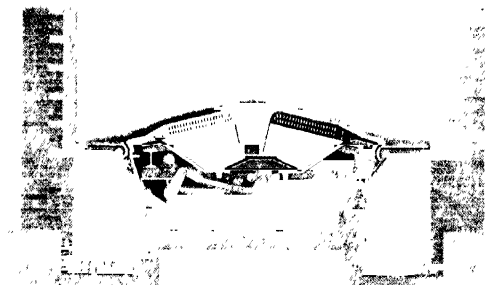
LATERAL RETORT STOKER (Front View)

has combustion grates sloping slightly from the central retort to the sides, where the refuse collects on dump plates which are operated at intervals of from two to six hours.

The Lateral-Retort Underfeed Stoker is a combination of the multiple-retort and automatic side-cleaning dump for boilers of 150 to 500 HP. Coal from the hopper passes to the main central retort, extending from the front to the bridge wall, by the action of the steam-driven ram and the main pusher blocks. There are a number of retorts branching out on both sides of the main retort, and the coal is forced sidewise into each lateral retort by pusher blocks operated by a separate steam cylinder, the pushers in adjacent retorts moving in opposite directions. The underfeed principle is thus retained even after the coal leaves the main retort, there being a gradual rearward and upward progress of the coal. The side dump plates have an auxiliary air supply to complete combustion of refuse before it is passed to the ash pits, which need only be 6 to 12 in. deep.
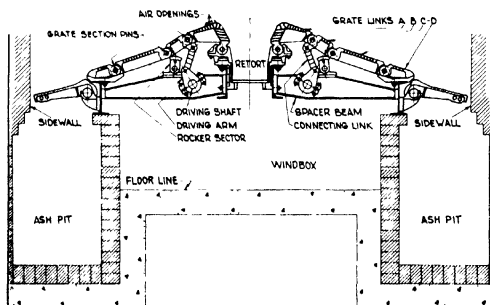
WESTINGHOUSE SINGLE-RETORT STOKER

The Westinghouse Single-Retort Underfeed Stoker is of the center retort type for most applications but for shallow, narrow furnaces a side retort is furnished when necessary to secure sufficient width between the retort and the dump grate to assure proper distribution and complete combustion. The fuel is fed into the retort by a main ram reciprocating under the hopper and is carried throughout the depth of the furnace by secondary rams in the bottom of the retort. The grate consists of parallel rows of narrow-link sections. The whole grate is mechanically operated by an oscillating shaft carrying cranks connected to driving arms. The effect is an undulating motion made up of vertical and horizontal components. This motion, which is adjustable for varying conditions, not only affords a positive movement of the fuel, but keeps the fuel bed in a porous condition Because of the agitation throughout the fuel bed, air is used at a low static pressure and with little excess. The dump grates are power operated, thus affording easy and quick cleaning
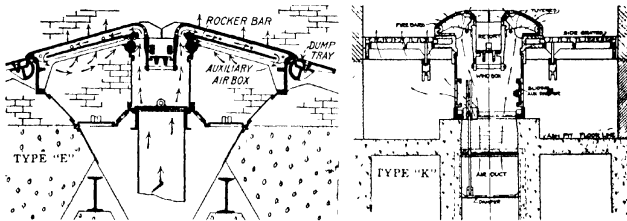
COMBUSTION UNDERFEED STOKERS

The Combustion Type "E" Underfeed Stoker has a single retort running back through the center of the furnace. The entire length of the retort bottom consists of a sliding member carrying the pusher block and the auxiliary pushers, providing positive coal feed. The grate bars at right angles to the retort are slightly inclined and are alternately fixed and moving. The moving bars have a short downward and outward motion, which may be regulated according to the requirements of the fuel, the active part of the fire being continuously self-cleaning. Air from the high pressure compartment passes through and cools the fire bars, and is discharged to the furnace at a temperature which facilitates combustion. The refuse travels to the ash dumps at the sides, and is discharged into shallow pits. The stoker burns a wide range of bituminous coals, and is applicable to boilers of any size, from 150 HP up. *Type "K" Stoker* is applied to small boilers, up to 200 HP. The retort and feed are similar to that of Type "E", and the grates adjoining the retort are of the shaking or dumping pattern. In the latter, a dead plate is inserted which extends out a short distance from the base of the tuyeres, the remainder of the space to the side walls being occupied by the dumping grates. Any grade of bituminous coal can be fired

The Frederick Underfeed Stoker is a 20° inclined multiple-retort stoker in which the secondary rams in the bed of the retorts contain tuyere openings for the admission of air, forming an active fuel-burning surface, and cooling the metal. The stationary tuyeres between the retorts have a curved vane design to provide proper guiding of the air into the fuel bed and an even distribution around the entire tuyere. Practically the entire
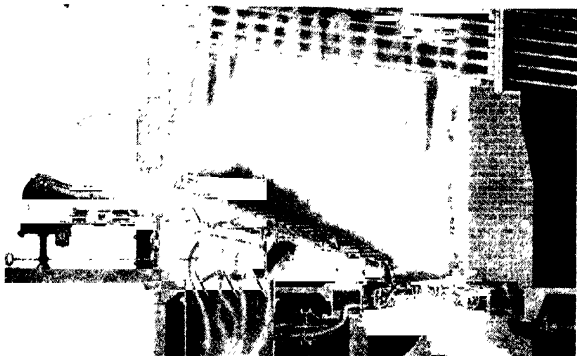
FREDERICK UNDERFEED STOKER

grate surface belongs to the underfeed section, the short stationary overfeed grate section between it and the active dumping grate section serving primarily for ash-storage space. Single or double, air-cooled dumping grates, with shaft protected from the ashes, are employed, or clinker grinders can be furnished where positive automatic discharge is desired. To prevent erosion of the front wall with high-volatile coals, a row of non-clinkering
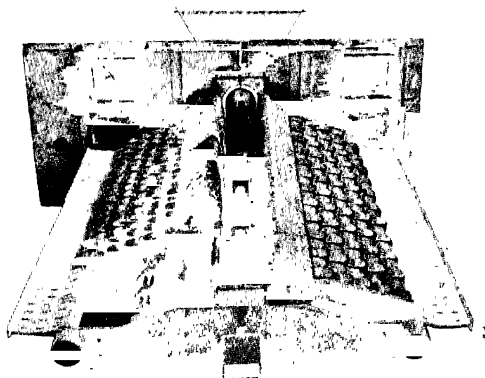
STURTEVANT UNDERFEED STOKER (Rear View)

furnace blocks is installed above the retort caps. Air from the stoker wind box passes through the hollow retort caps, cooling them, and then passes across the fuel bed through the perforation of each block, over-coming any deficiency of air which might exist at this point. The stoker is built in "central-station" and "super-station" types

The Sturtevant Underfeed Stoker includes a centrally-located hori-zontal retort provided at its upper edges with stationary tuyeres, through which air is introduced to the fuel as it rises into the fire. It is fed to the retort by a power-driven ram, is distributed by pushers reciprocating with the ram, and spread uniformly over the entire furnace area by means of lateral reciprocating grates. A homogeneous bed of coke is maintained over the top of the retort, and is delivered to the moving grates only as fresh fuel is fed, permitting the retort to work continuously at its maximum capacity, maintaining an even distribution of fuel over the furnace area. Continuous maximum loads or fluctuating loads can be handled. The stoker is adapted for any grade of bituminous or semi-bituminous coal or any mixture having sufficient coking qualities to bind the fuel.

The McClave Underfeed-Overfeed Stoker receives coal from the hopper onto a coking plate extending across the furnace, from which it is underfed to the inclined grates by mechanically operated plungers or pushers, the period between strokes being adjustable instead of the motion. The arch over the coking plate is of ribbed cast iron and hollow to conduct air to the coking area, and is surmounted by plain 9-in. firebrick. Kicker bars, which form part of the sloping grates, can be operated differentially to receive a quarter, half or full kick, either simultaneously or separately. Sifting is reduced to a minimum, giving less opportunity for the formation of holes. The ash-dumping or cut-out bars consist of a main bar with sectional cut-out fingers set in slots Bituminous and lignite fuels can be burned, mixed, if desired, with anthracite screenings or coke breeze.
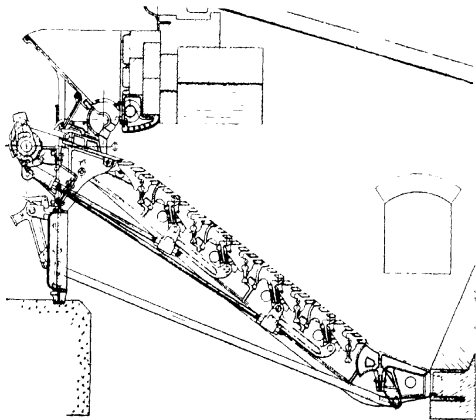
McCLAVE STOKER
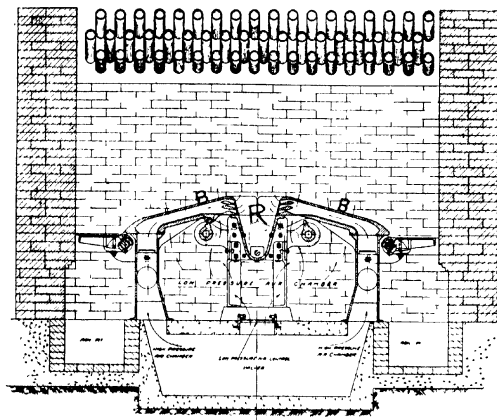
ROACH UNDERFEED STOKER

In the *Roach Stoker* the coal is fed through a central retort R from a hopper in front, by means of a steam ram. On both sides of the retort are alternate live and dead grate bars sloping slightly down to the side walls. In the hollow bar type, air from the high-pressure chamber enters the front end of the bars and issues heated at the retorts, where it mixes with the distilled volatiles, while low-pressure air is bled from the high-pressure chamber to the low-pressure chamber under the bars.
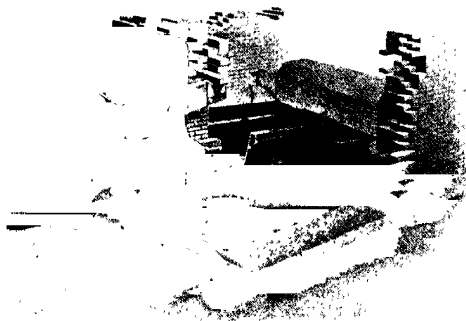
MOLOCH UNDERFEED STOKER

The Moloch Stoker has horizontal retorts into which the coal is fed from the hopper by steam rams delivering about 10 lb. per charge. One or several parallel retorts are used in each furnace. At the top of the retorts are perforated tuyeres *T*, level with the surface of the dead plates. The air under pressure circulates through the chamber under the dead plates and issues from the tuyeres. Type "H," illustrated, is manually cleaned, while type "S" is self-cleaned.
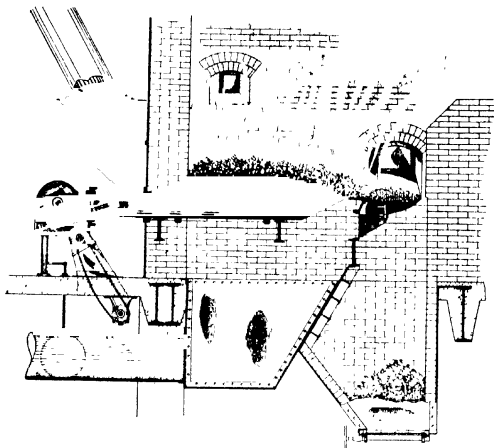
DETROIT UNDERFEED STOKER

The Detroit Multiple-Retort Underfeed Stoker contains a number of closely-spaced horizontal retorts, along which the fuel is fed with a positive movement. The mechanically-driven rams are adjustable, as are also the auxiliary pushers. Air is supplied at low pressure through openings in the tuyeres, which face toward the inside of the retorts, also through side-wall tuyeres and through adjustable ports in the front wall. The ash dump plates are counter-balanced, with a worm gear reduction, making hand operation possible even with the largest stokers. A similar design of single-retort stoker, equipped for side-cleaning, is used with forced draft for boilers up to 250 HP., while the Detroit V-type overfeed stoker is used with natural draft. The latter is V-shaped in section viewed from the front of the furnace, the coal being fed at the sides and flowing down the inclined grates to a clinker crusher at the bottom of the V.

David C. Spencer states that the **power dump** is particularly suited for plants subject to fluctuation in load. When overloads come, it is possible to feed and burn coal at a rapid rate and discharge the ash, even though the latter may contain combustible, with not over half a minute's

A. POWER DUMP WITH PLATE   B. SCRAPING SLAG FROM BRIDGE-
          DROPPED   WALL—*The Central Station*

C. SINGLE-ROLL ROTARY ASH DISCHARGE—*The Central Station*

interruption. Fig. A shows ash dropping through an opened dump plate, after which the latter is raised above running position to scrape any slag from the bridge wall, and replaced in a horizontal position until required again. With fairly constant load, **a rotary ash discharge** makes it possible to maintain clean fires by discharging ash at the rate at which it is formed. The ash pocket serves to hold the refuse while the remaining combustible which it contains is burned out by air admitted through the lower extension grate *A*, Fig. C, and to cool it before it passes to the rolls. The crusher plate *B* is hinged at the top, to permit varying the size and rate of discharge of the refuse, while the crusher roll *C* is built of cast iron shells carrying cast iron teeth of triangular cross section, and mounted on a square steel shaft. The roll in the illustration revolves to the left. With a double setting (two stokers discharging through a common ash pocket) or in other cases where two rolls are used, they rotate away from each other at the top, and two crusher plates are used.

The rotary discharge affects materially the combustible in the ash, which has been one of the largest losses in connection with stoker firing, 15 to 25% of the refuse being combustible. With proper proportioning of the stoker for the coal burned at high ratings and with the proper depth of ash well, this loss has been cut in half. In the Hell Gate installation (page 370), when operating at 180% of boiler rating, the refuse was 4.44% combustible, representing a loss of only 0.4% of the heat in the coal. One of the features of this system of ash discharge is that the ash is broken up into small pieces and cooled to the point where it can be disposed of by bucket conveyors, flushing by water or by any other method commonly employed. The proportioning of the well in connection with the rest of the stoker is very important for different coal conditions. In some cases this ash well is 6 ft deep, and for each particular depth there is a width that is required, so that the ash coming from the major fuel bed will have a continuous flow down through the ash well and through the crushers. Figure F, on page 364, shows the largest stoker built up to 1924, equipped with a Taylor Rotary Ash discharge, at the Kearny, N. J., station of the *Public Service Production Co.* This stoker is 16 retorts wide, 37 tuyeres deep, furnace width 26 ft, height from bottom of crusher rolls 16 ft, fuel burning capacity over 64,000 lb per hr

According to *Charles H. Bromley* a successful clinker grinder must have cool clinker in contact with the grinding roll, this being secured by using a pit of adequate depth, which will contain a sufficient mass of material to resist the passage into it of air from the overfeed or other parts of the stoker. The agitation and breaking up of the clinker should take place at the point of air supply, before dropping into the pit, as any further combustion in the pit will only serve to heat and make trouble with the rollers. The latter should discharge the clinker in small particles, cool and reasonably dry, and an air or water-cooled back should be provided for the brick wall side of the pit, to prevent clinker adhesion.

C. M. Garland illustrates in Fig D a furnace for an underfeed stoker burning a fuel of high moisture content, with a stratification loss of only 2 or 3%, and in Fig. E a furnace for high ratings and easily-ignited fuels, which would however require high settings or the use of jets admitting products of combustion for mixing the combustible and combustion-supporting gases coming from the stoker.
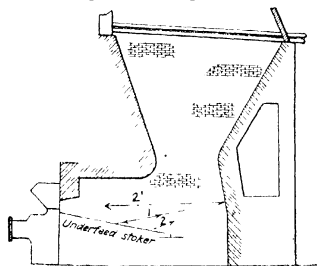
D. FURNACE FOR UNDERFEED STOKER, HIGH-MOISTURE COAL
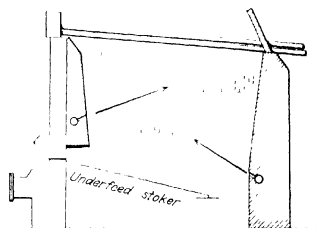
E. UNDERFEED STOKER FURNACE FOR HIGH RATINGS AND EASILY-IGNITED FUEL.—*Power.*

A. POWER DUMP WITH PLATE   B. SCRAPING SLAG FROM BRIDGE-
          DROPPED   WALL—*The Central Station*

C. SINGLE-ROLL ROTARY ASH DISCHARGE—*The Central Station*

interruption. Fig. A shows ash dropping through an opened dump plate,
after which the latter is raised above running position to scrape any slag
from the bridge wall, and replaced in a horizontal position until required
again. With fairly constant load, **a rotary ash discharge** makes it
possible to maintain clean fires by discharging ash at the rate at which it is
formed. The ash pocket serves to hold the refuse while the remaining
combustible which it contains is burned out by air admitted through the
lower extension grate *A*, Fig. C, and to cool it before it passes to the
rolls. The crusher plate *B* is hinged at the top, to permit varying the
size and rate of discharge of the refuse, while the crusher roll *C* is built
of cast iron shells carrying cast iron teeth of triangular cross section, and
mounted on a square steel shaft. The roll in the illustration revolves to
the left. With a double setting (two stokers discharging through a com-
mon ash pocket) or in other cases where two rolls are used, they rotate
away from each other at the top, and two crusher plates are used.

Thus the bridge wall is back where it gets less direct heat from the incandescent fuel bed and less erosion from the hot furnace gases, the wide mouth of the first pass exposes the maximum amount of tube surface to the radiant heat of the fire, and the shape of the first passage provides for shrinkage of the cooling gases, so that maximum capacity may be developed without too high entrance velocity. The gases thus have more time to complete combustion, carrying fewer fine particles of slag to the tubes, and the area is so large that slag can collect for several weeks without undue draft restriction. Fig. H shows another setting with contracted gas passage, over double stokers. The drop-header construction permits the use of a short horizontal shelf S on top of the second row of tubes, from which soot is easily removed. The two lower rows of tubes are entirely in the furnace chamber and exposed to radiant heat. Such baffles are built of corrugated tile 4 in. wide, laid through the diagonal alleys between the tubes, with a single form placed on the front side of the wall. The space around the tubes and between the tile is filled with an air-hardening fireproof plastic material which does not bond either with the tubes or the tiles, so that tubes are readily withdrawn at any time and replaced by others slipped through the same holes. The baffles are built at any slope, as they are supported by the tubes and have no metal backing to overheat and force them out of place
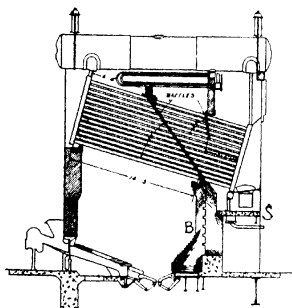
G. JUG-SHAPED FURNACE REFLECTING HEAT ON ENDS OF BOILER TUBES
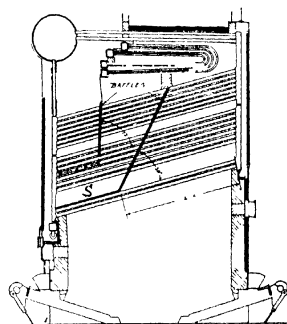
H. FURNACE WITH DOUBLE STOKE
—*Power Plant Engg.*

Geo. I. Bouton gives, in Fig. I, illustration of a V-type underfeed stoker set in a Dutch-oven furnace in front of a 500-HP. Stirling boiler.

Edwin B. Ricketts states that air-cooling of furnace walls in which stokers are operated at high capacity is objectionable, because if the air is under pressure, leakage will occur into the setting, and if under suction leakage will be into the air chambers, increasing the tendency to destroy the refractories.

Fig. J shows an underfeed stoker setting in which the side walls S and even the back wall of the clinker pit C consist of elements resembling radiation superheaters, through which boiler water circulates. The upper part of the back wall forms the radiation superheater, receiving steam through Q and discharging through T.
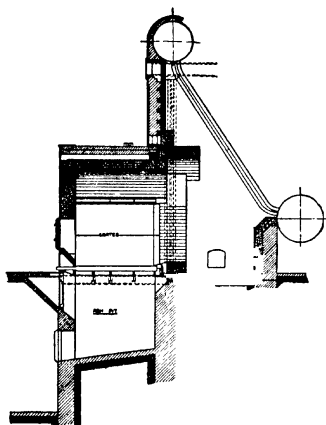
I. DUTCH-OVEN SETTING FOR
   V STOKER—*A.S M E*

J   WATER-COOLED   COMBUSTION
   CHAMBER —*Z d V dcut. Ingr.*

K. ROTARY FURNACE-WALL PLATE
      —*Power*
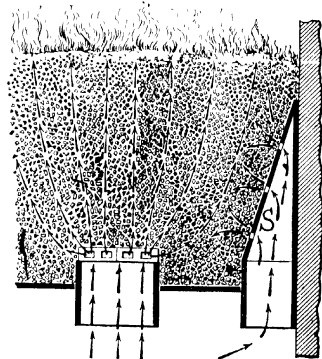
L. SPECIAL SIDE-WALL TUYERE
      —*Power*

Hugh R. Carr describes a special tuyere, Fig. L, for use with under-feed stokers to prevent side-wall clinker. The side-wall tuyere *S* is so built that the air from it is directed toward the center of the fire instead of up through the fuel along the side-wall, so that this coal does not ignite till it reaches the dump grate or clinker grinder, where it burns. In Western plants, many of the old tuyeres have been replaced by this design, and even with Eastern coals, it has been found to triple the life of the side-walls.

Fig. K shows a rotary plate used to prevent side-wall clinker, built of renewable sectors of tile or cast-iron, and slowly revolved on a horizontal shaft in the air chamber below the grate, so that any clinker collecting on it is scraped off against adjacent grate blocks.
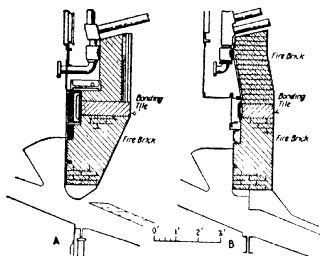
M. A BAD AND A GOOD DESIGN OF
    FURNACE FRONT WALL
                —A S M E

E. B. Ricketts calls attention to the care required in designing front walls used with underfeed stokers and modern high-set boilers, due to the softening of bricks at temperatures 500° to 600° F below their melting point. *A* in Fig. M shows a wall which was corbeled in such a way as to impose a heavy load on the course of bricks just above the ram-box caps, and which failed due to softening of the lower row of bricks. The improved design shown to the right gave several years' service with no trouble.
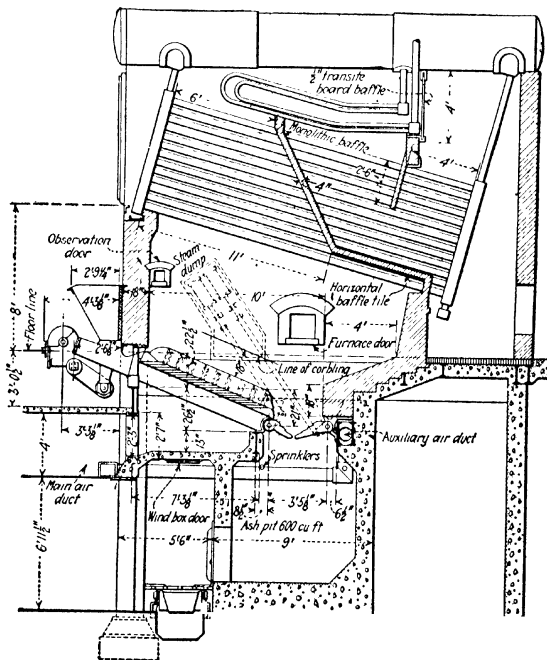
N. UNDERFEED STOKER WITH 5560 SQ. FT. BOILER—*Power*

Power describes an underfeed stoker and 5560 sq. ft. boiler installation, **Fig. N**, designed to increase capacity and flexibility, when used with low-grade clinkering coals, high in ash, sulphur and moisture. The fuel as it is introduced from the retorts by the rams is spread laterally by deflector plates so as to cover the surface of the tuyeres. Secondary step shaped rams, located midway between the deflector plates and the grate tuyeres, extend in their action practically to the dump plate, filling in blow-holes and insuring a continuous movement of a fuel bed of uniform thickness, with a slight agitation of the lower bed. Extension tuyeres, admitting a limited amount of air, protect the front and side walls from clinker, and the gases are mixed by a battery of steam jets. One dump plate is hinged to the lower end of the stoker and one to the rear wall support. These are steam operated, and have an auxiliary air supply. The boilers were rebaffled to secure constant gas velocity. The bridge wall rises from the dump grate to the fuel bed level and then recedes to the rear, and 90% of the lower tubes is exposed to direct radiation, with a minimum of reflecting surfaces subject to deterioration. On account of anticipated reduction of gas temperatures, the superheater was increased from 550 to 900 sq. ft. The rear baffle was built of "Transite" board. Efficiencies on test ranged from 77% at normal rating down to 60% at 350% of rating, the average being 70% for poor fuel and variable load.
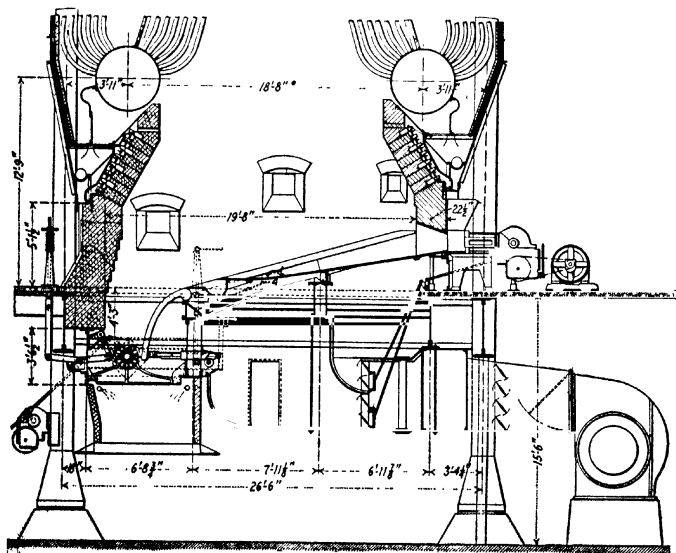
O. UNDERFEED STOKER AND STIRLING BOILER—*Power*

E. E. Dubry describes a single Riley stoker, Fig. O, used under a 23,654 sq. ft. Stirling boiler which had formerly been fed by two stokers from opposite sides, the change being made with the idea of reducing the cost of overhead bunkers and coal-conveying equipment. It has a total grate area of 470 sq. ft., with 13 retorts, fed by rams 11 in. in diameter with 12 in. stroke. The tuyeres or grate blocks are movable in a direction parallel to the path of the coal. The length of travel is adjustable and under control of the operator, but the period of oscillation is dependent upon the stoker speed, since each complete tuyere box, from the point where coal enters to the end of the apron at the grinder, is driven by its corresponding ram.

W. C. Strunk describes an investigation as to the stratification of gases in a furnace under a 15,290 sq ft. boiler, with a double stoker having 13 retorts front and rear, shown in Fig. A. Fig B gives the average CO_2 content across the furnace when operated at 310% rating, both with old-type side-wall tuyeres, which resemble the inner tuyeres, and extension-type tuyeres, which pro-
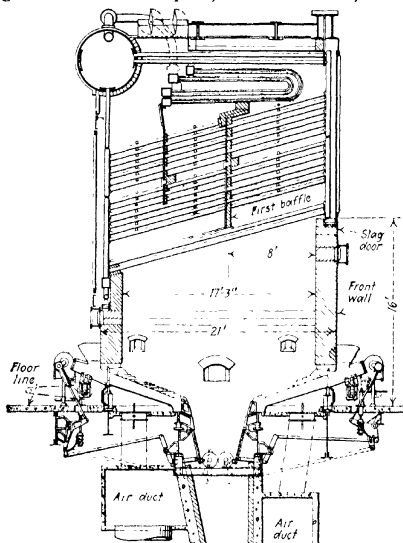
A. WATER-TUBE BOILER WITH DOUBLE UNDERFEED STOKER—Power
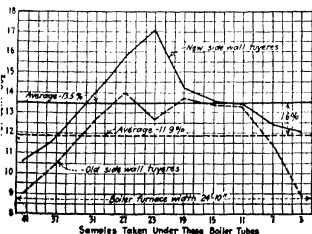
B. FURNACE-GAS COMPOSITION UNDER BOILER TUBES
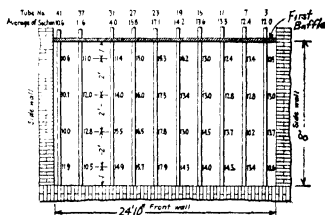
C. PLAN VIEW OF POINTS IN FURNACE WHERE GAS SAMPLES WERE TAKEN AND PERCENTAGES OF CO_2

ject up and protect the walls and which also contain air outlets. The latter type caused an increase of CO_2, particularly at the sides. Fig. C gives the individual analyses at 40 points in the plane just below the tubes, in the first pass, when operating at 364% of rating, and shows the high CO_2 content in the center of the gas current.
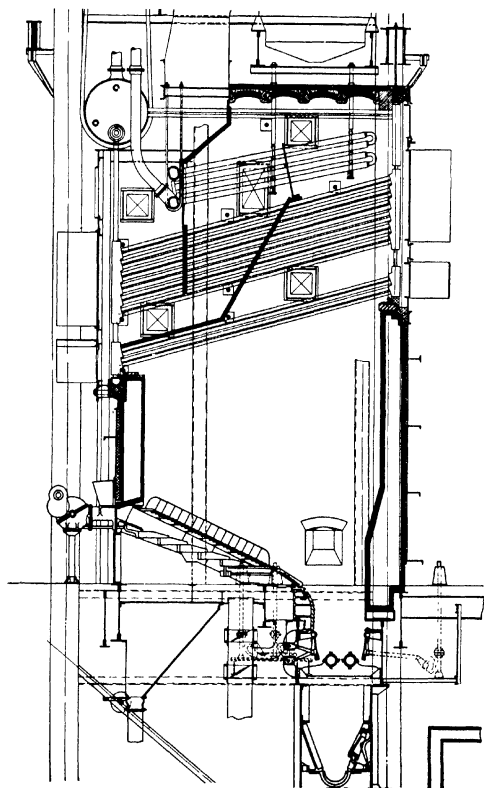
D. 1590 HP. BOILER AND UNDERFEED STOKER AT HELL GATE STATION

The above Figure D shows a 1590-HP. boiler at Hell Gate Station, New York City, designed by *T. E. Murray Co.* The side wall is replaced

by vertical 4-in. tubes, 2 gages thicker than standard, set on about 7-in. centers, with vertical fins welded to the tubes, overlapping and closing the space between tubes, backed by layers of brick, Sil-o-cel and a steel jacket. These tubes absorb 45,000 BTU per sq. ft. per hr. The boiler heating surface is 15,900 sq. ft., superheater 7430 sq. ft., and economizer 13,800 sq. ft. Each boiler is fired by a *single* long-retort Taylor under-feed stoker, with a deep ash-discharging mechanism. Tests showed a maximum efficiency of 92.7% and a maximum driving rate of 528%.

Rating	170%	181%	528% (¾ hr.)
Efficiency, not considering economizer.	83.2%	84.6%	.....
Efficiency, including economizer.......	89.6%	92.7%	.....
CO_2 leaving boiler...................	11.69%	13 04%	15.2%
CO_2 entering economizer	10.91%	12.01%	13.8%
CO leaving boiler....................	0.06%	0 04%	3 3%
CO entering economizer.............	0.04%	0 03%	4.0%
Excess air, leaving boiler......	60.1%	38.4%	.....
Excess air, entering economizer.......	71.6%	49.7%	.....

The high CO in third column is due to insufficient furnace capacity when forcing boiler at this rating.

Oscar J. Richmond states that to start a fire in a cold underfeed stoker, fuel should be fed from the hopper to a depth of about 8 in., and the machine stopped while a man digs a trough in the top of the bed parallel to the front of the stoker. This is filled with kind-ling or with red-hot coke, and a light draft is furnished for about two hours, after which the rams are started and the regular forced draft used When the combustion rate is to be increased, the air supply is increased, then the stoker speed is adjusted to keep the fuel-bed thickness constant, say at 26 to 30 in. The action of the upper ram of the Taylor Stoker varies only with the shaft speed, and the lower ram is set for long stroke only when
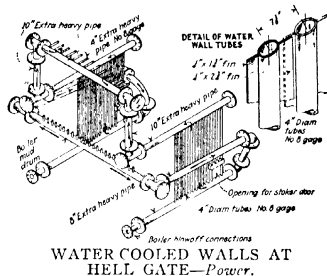
WATER COOLED WALLS AT
HELL GATE—*Power.*
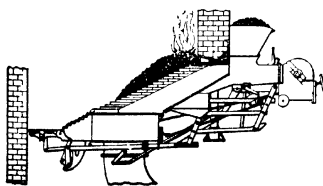
KINDLING A FIRE WITH RED-HOT
COKE
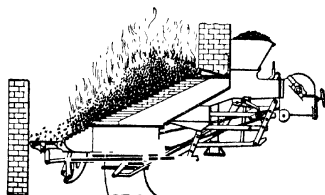
CONTOUR OF A PROPERLY-REGU-
LATED FIRE.—*Power*

necessary to remove an accumulation of clinker from the lower part of the tuyeres, or to re-cover the dump plate after dumping. Ash should be dumped when it is 12 to 15 in. deep on the plate, at which time the stoker rams are stopped and the air turned on to the extension grate to burn any coke which may be there.

H. T. Edgcomb describes a method adapted for firing underfeed stokers with the "balanced draft" system of back damper regulation for maintaining a constant draft over the fire, using a "3-in-1" draft gage. The boiler setting is first gone over and made as tight as possible, the draft gage checked to see if it is correct, the balanced regulator adjusted to maintain about — 0 05 in. over the fire, fire cleaned and built up to what seems the proper thickness. Then, disregarding the draft gages, the windbox pressure is adjusted till the CO_2 is 12 to 14%, and the drafts recorded, say 2 in. in the windbox, — 0 05 in over the fire and — 0.6 in. at the stack damper. The fireman is then instructed to hold the stack damper gage at — 0.6 in. by adjusting the windbox pressure, and if he has to put more than 2 in. pressure in the windbox to do this, the fire is getting too heavy or dirty and the stoker engine should be slowed or fire cleaned. If he cannot put 2 in. in the windbox and keep — 0 6 in. at the stack damper, then the fire is too light or there are holes in it, and the fire must be leveled or stoker speeded up.

According to the operating code of the *Philadelphia Electric Co ,* holes in the fire bed are caused by stoppage of coal feed or by uneven resistance of the fire bed to the passage of air, a condition which occurs when the fire is clinkered or too thick elsewhere, or on account of improper relation of stoker speed to wind-box pressure Holes in the clinker crusher pit are caused by improper adjustment of the crusher doors or by excessive speed of the crusher rolls The following remedies are suggested: Increase the stoker speed, cutting out the sections in which the fire may become too heavy. Decrease the forced draft, if possible. When a hole is near the front wall open the extension damper in the section in which the hole occurs See that coal is feeding into the rams at which holes occur and, if it is not, use wooden rods to force the coal to the rams. If a hole is in the rear, put on the long stroke and close the extension damper.

BURNING LOW-GRADE AND WASTE FUELS

Anthracite Culm.—The burning of loose slush or culm is attended with difficulty, but results in economy when it can be successfully accomplished. At the Nanticoke plant of the *Delaware, Lackawanna & Western R. R.,* power is generated from anthracite culm from the washeries, consisting of particles under $\frac{3}{32}$ in. in diameter. It is burnt on Coxe chain-grate stokers of special design, the grate fingers containing openings $\frac{1}{16}$ in. by $\frac{3}{32}$ in., making up about 6% of the grate surface. A fire bed about 4 in. thick is carried, and a draft of $1\frac{1}{2}$ to 2 in. used.

At Hauto, Pa., the *Lehigh Coal & Navigation Co* operates a 100,000 Kw. plant on anthracite refuse running from 9000 to 11,000 BTU per lb Some of the boilers have Coxe traveling grates, and others hand-fired dumping grates of the Acme slotted or pin-hole type. 6% of the grate surface is used for air-holes, which are at the bottom of grooves, like a

waffle iron. Double fire-arches are used, both on account of the air-cooling thus secured, and as a reserve in case of the failure of one. Cinder-catchers prevent fuel being carried beyond the first pass.

W. S. Hachita, of the Lehigh Valley Coal Co, states that anthracite culm amounts to 7½% of the amount mined, and that it contains 70 to 85% combustible. Experiments made at Hazleton showed that a mixture of 30% culm with coking bituminous coal produced an evaporation equal to that with the bituminous, and that the mixture was easily burned, as it did not cake up.

B. S. Murphy, of the Hudson & Manhattan R. R., reports burning anthracite coal containing 60 to 80% dust, by the addition of 5 to 20% soft coal, on inclined dumping grates. He begins with a fire 3 to 5 in. thick after firing, and builds it up slowly to 16 to 18 in. before cleaning, burning an average of 23 lb. per sq. ft. per hr. Considerable soot is formed, 2½ to 3 in. draft is used at rating, and 4 to 7 in. at peak load. Coxe chain grates are being adopted in these plants.

Wm. P. Frey, of the Lehigh Coal & Navigation Co., recommends the mixing of No. 3 and 4 buckwheat with soft coal, if clean and the mixing is well done, and states that this does away with hard clinkers. The green coal should be thrown on when the fire is white hot, as after leveling, which tends to bake the No 4 to a fuel of pea size. The fire must be kept loose at all times and will stand very hard blowing. He considers almost any kind of grate bar suitable, up to ¾ in openings, provided enough kindling is left after cleaning to cover the grate. With natural draft 20% of culm can be used, and with forced draft up to 35%.

W A. Shoudy and *R. C. Denny* describe experiments as to the character of settings to be used with 1345-HP B. & W. boilers, each equipped with two Coxe chain grates, for burning "No. 3 Buckwheat" or "birdseye" anthracite, the specification for the fuel being not less than 95% to pass through a ³⁄₁₆-in. and not over 20% through a ³⁄₃₂-in. round-mesh screen. Fig. *A* shows the conventional single-arch setting, which gave as high combined efficiency as could be obtained with this type, the arch serving to shield the front or ignition end of the grate from the cooling effect of the boiler tubes, while the furnace is well designed and has a large combustion volume, the front header being 18 ft 6 in. above the boiler-room floor. There was, however, a tendency for the gases from different sections of the grate to stratify, a high carbon content in the ash unless excess air was used, loss of fines in ashpit and breeching, and difficulty in meeting sudden load changes. A duplicate of the boiler shown in *A* was equipped with three arches, as shown in Fig. *B*, and proved more satisfactory from a combustion standpoint, although carbon and slag accumulated on the top of the rear arch to within a foot of the upper arch. This reduction in gas passage caused an increased draft drop of only 0.2 in. of water, and in the two-arch setting finally chosen (Fig. *C*), the advantage of a restricted throat for mixing the gases was retained, without the slag-catching ledge. As shown in Fig. *D*, the two-arch furnace checks well in efficiency with the three-arch furnace up to 250% of boiler rating, which is exceeded only in emergencies. Fig. *E* shows the gas analyses in a vertical plane 30 in. from the side wall and for points a foot above each of the six blast compartments under the stoker, also in the first and third boiler passes, for the three-arch furnace operated at

275% rating. The fuel bed gradually decreases in thickness as it travels back. At this rating some air is admitted to the first five compartments under the stoker, but none to the sixth. Over the first four compartments the fire is to some extent a gas producer, although only a moderate amount of CO (6%) is produced over the first, the CO_2 being a little in excess of 14% at this point. The CO increases up to nearly 12% over the third compartment, while CO_2 decreases to about 7% until the fifth compartment is reached, where excess air is admitted to burn the ash clean, the free oxygen increasing to about 12% and CO disappearing entirely. Immediately over the sixth compartment, the small quantity of gas ascending is practically pure air. The middle group of curves shows that combustion is practically complete at the bottom of the first pass, with CO nearly all burned out, and very little free oxygen except at the back of the pass, near the baffle, due to persistence of stratification through the tortuous path past the arches. The presence of 16% CO_2 except near the baffle shows that a practically minimum amount of excess air has been used on this longitudinal section of the fire. The upper group shows substantially the same CO_2, uniformly low CO, and higher O_2, presumably due to air inleakage. The furnace was also operated at the same rating but with somewhat higher pressures in the second and third air compartments, which lowered the CO_2 and increased O_2 over Nos. 2 and 3 and greatly reduced the CO over the No. 3. The air pressure at the fourth compartment was carried a little lower than in the run shown in Fig. E, so that the excess air at this point dropped nearly to zero and the CO_2 rose to over 16%, while over No. 5 there was a characteristic disappearance of CO and great increase in O_2, and over No. 6 the analyses were similar to those in the previous run. Runs were also made at 134% rating with much less air pressure under all compartments, under which conditions the CO rose from about 7½% over No. 1 to about 17% over No. 4 and then fell to zero. Practically no O_2 was found except over Nos. 5 and 6. The CO_2 ran a little less in the forward part of the fire, increased to 12% over No. 5 and dropped to zero over No. 6. The runs show to what extent an anthracite fire can be made to operate as a gas producer and still retain its properties of continuous operation. Fig. F shows the result of seven temperature and CO_2 readings at points at top of third pass of the three-arch furnace, distributed across the width of the setting, representing two stokers separated by a 3-ft. center wall. All curves show marked drop at center and edges, and the importance is indicated of averaging the samples of gas if only one analysis is to be made. Averaged samples were used in the heat balances, but single samples for the study shown in Fig. E.

The tests showed that either the three-pass or two-pass furnace practically eliminated stratification, carbon loss in the ashpit, and ignition troubles, even with low-grade coal, although there is room for improvement at ratings above 250%. Practical operation with river coal containing 60% undersize and 33% ash showed that the maximum rating with the single-arch furnace was 190%, but with the two-arch furnace 300% could be secured, and at the usual operating rating of 225% the efficiency was seen to be higher than with the single-arch furnace, although no formal tests were made with the undersize coal.
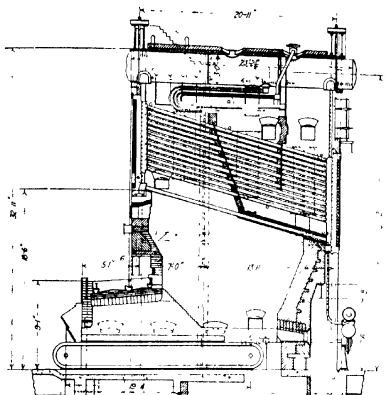
A. CONVENTIONAL SINGLE-ARCH FURNACE FOR BUCKWHEAT.
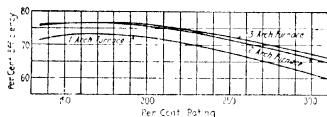
D. EFFICIENCIES OBTAINED.
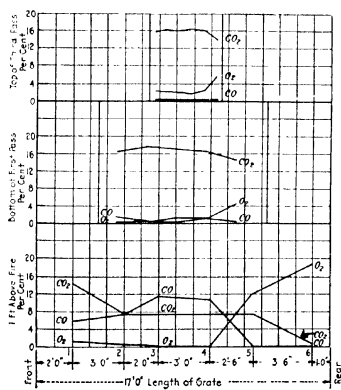
E. FLUE-GAS IN THREE-ARCH FURNACE, 275% RATING.
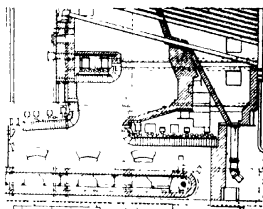
B. TRIPLE ARCH FURNACE
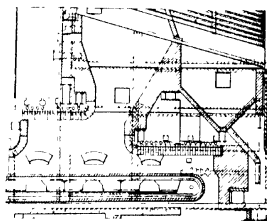
C FINAL DOUBLE-ARCH FURNACE
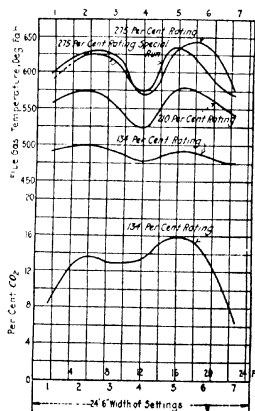
F. TEMPERATURE AND CO_2 ACROSS TOP OF THIRD PASS OF THREE-ARCH FURNACE—*A.S.M.E.*

Survey Rating	No 26	No 4	
Flue Temp	201	195 %	
Stoker Speed	6.5	652 Deg F	
Flue Gases CO₂	39	48 Ft per Hr	
	16.3	%	
O₂	2.4	%	
CO	0.0	%	

Actual Effect of a Rear Arch
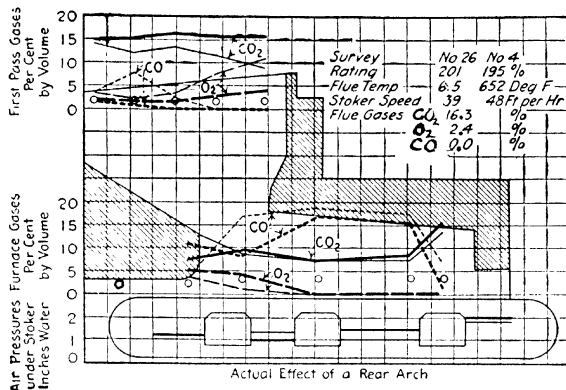
G   CHAIN GRATE FOR BURNING SMALL ANTHRACITE—*Power*

A. R. Mumford describes a series of tests made to determine the most desirable method of burning small sizes of anthracite on Coxe chaingrates under a four-drum Edge Moor boiler with 10,000 sq. ft. of heating surface, 29 and 30 tubes wide and 16 tubes high   Standard baffling was used, the gases crossing the tubes three times. The original furnace was substantially as in Figure G, but without the rear arch shown at the left (distance between two parallel lines equals 1 ft.). Gas samples were taken at six points, shown by small circles, about 6 in. above the fuel bed, and at five points in the entrance to the first pass, in a plane just below the tubes. The *light* lines (solid, dotted and dashed) represent the gas composition for Survey No. 4, with the setting in the original condition. Considerable *CO* was produced from the front third of the stoker, while practically pure air came through the extreme rear, where the arch appears in the figure, there being little combustible in the bed there. However, particles of solid combustible were blown from the front of the grate and carried in suspension to the rear, where they fell unconsumed to the ash pit. The gases entering the boiler pass were high in O_2 in front, the *CO* having been burned by the excess air, while at the rear there was high *CO* and insufficient air. Considerable *CO* was found in the flue gases, although some *CO* was burned while crossing the tubes, giving high exit temperatures. Higher air pressure was tried under the rear of the stoker, but the ascending current clung to the bridge wall, and no improvement was noted in mixing the air and gases. Raising the front arch one to two feet reduced the gas velocity and allowed less combustible to be blown to the rear, but the main stream of gas did not go as far back as with the low arch, and the excess air was increased. An air-jet at 25 lb. was then introduced through the side-wall about a foot below the end of the (low) front arch, and although this consumed the *CO* before it entered the boiler, undue excess air was introduced, and it was thought better to force the necessary air through the bed, thus mixing it with combustible gas and

also burning an additional amount of solid fuel   To show the probable effect of a rear arch, steam jets were introduced just above the rear of stoker, which did not affect the conditions on the fuel bed, but directed forward the air entering through the refuse and mixed it with the main gas stream, eliminating CO and increasing the CO_2 in the gases to the boiler.   A similar arrangement was tried with the *high* arch, but the earlier turning of the main stream with the latter and the shorter distance between the arch and the tubes made it more difficult to mix the gases from the rear of the stoker with the combustible gas. As the rear arch with low front arch seemed to be the most favorable combination, confirmation tests were made with a *Detrick* flat-suspended arch as in the figure, the resulting gas compositions being shown in the *heavy* lines of the chart, for Survey No. 26. The suspended solid combustible was carried to the roof of the rear arch, where it burned and flowed slowly toward the grates, forming "whiskers" on the nose of the arch. The air pressure under the rear of the stoker was kept higher and the refuse passing over the end of the stoker appeared well burnt out. A single current of gas of uniform composition entered the boiler pass, and only $\frac{1}{20}$ of the CO formed in the fuel bed entered the boiler, as against $\frac{1}{5}$ without the rear arch, while the flue gas temperature was reduced by 35° F   The tests confirmed the desirability of the Dutch-oven type of furnace, and of having the combustible gases from the front section of the grate forced back where they will come in contact with the free oxygen coming up through the refuse section   Instead, however, of extending the main arch all the way back, where it would be subject to destructive temperatures, the rear arch is used to deflect forward the air from the rear section and both arches are somewhat cooled by radiation to the boiler

   Fig. H shows a furnace built for burning anthracite, but modified by the addition of arches so that a mixture of No. 3 buckwheat anthracite and bituminous slack could be used. With forced draft, 150% of boiler rating can be maintained on peak loads, without violation of smoke ordinance

   Briquettes.—The making of anthracite culm into briquettes permits the transportation and combustion under favorable conditions of fuel which might otherwise be unutilized. According to *W. H. Wakeman,* the coal is crushed between corrugated rolls or wheels, or between pivoted jaws   If a bond is used, it should preferably be combustible itself.   25% bituminous coal gives good results, or 5% bituminous and 5% pitch. The bond and the culm are thoroughly mixed in screw conveyers, which proportion the ingredients by their relative feeding speeds   When made without bond, the briquettes may be moulded wet, as with a brick machine, or dry, in which case they are subjected to high pressure, 3,000 to 4,000 lb. The pressure may be applied in a reciprocating press, or the ground culm may be passed through rollers containing recesses for shaping the material.   One of the most satisfactory of these turns out spheres $2\frac{1}{2}$ in. in diameter.

   The combustion of **coke** in general requires larger grate area and draft than coal, due to its greater bulk and difficulty of ignition. Fig. I shows a modified chain grate construction for this purpose. The incoming coke is brought to a bright glow over an inclined contact hearth and moves onto the grate at a depth of 16 to 20 in. The coke should be $\frac{1}{2}$- to $1\frac{1}{2}$-in. pieces, The auxiliary hopper acts as a gas producer, forming carbon
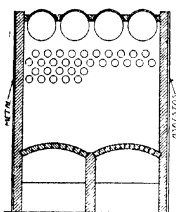
H. FURNACE FOR MIXED COAL.—
Power Plant Engg.

J. COMBINATION COAL AND COKE
HOPPER—Elec. World.

I. SETTING FOR BURNING COKE—
Elec. World
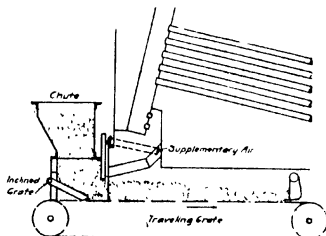
K. FIREBAR FOR COKE BREEZE—
Soc. of Chem. Industry

monoxide, which is burned by secondary air admitted to the combustion space by tubes passing through the fire arch. Slag pockets are used at the end of the grate to prevent the entrance of too much air at that point.

Except with abnormally large grates, peaks should be taken care of with coal or mixed coal and coke firing. Fig. J shows a feeding hopper designed to control the supply of coke and coal in layers of varying depth on a chain grate.

Coke Breeze, the fine material washed from the quenching tables and grading screens of gas works and by-product coking plants, is being used as fuel in England, according to *J. B. C. Kershaw*, although it contains 20 to 30% ash and 10 to 20% moisture. When burned alone, external furnaces of the Dutch-oven type are recommended, with water tube boilers and forced draft. The radiant heat from the furnace can be utilized by means of hollow walls to preheat the air. When mixed with bituminous coal, it can be fed to a chain grate equipped with two hoppers, from which varying proportions can be fed, the coke forming the lower layer on the grate.

P. Parrish states that coke breeze is burned under Lancashire boilers, in English chemical plants, on fire-bars of the type illustrated, Fig. K. The

primary air enters through the larger horizontal openings, which extend back at right angles to the front of the furnace, the flow being induced by steam nozzles, while the secondary air, induced by chimney draft only, is delivered back of the bridge. The fuel bed is so regulated that sufficient primary air is introduced to burn most of the fuel completely to CO_2, no attempt being made to secure two-stage combustion. Fires are cleaned every four hours. *H. M. Ridge* states that it is desirable to use division walls to cause efficient mixing of the secondary air with the combustible gas from the fire grate.

Walter N. Flanagan states that coke breeze can be burned on almost any forced-draft stoker or grate, and that with underfeed stokers, up to 20° slope, there is almost no avalanching or running of the fuel even when straight breeze is burned. The efficiency with breeze or with mixtures is less than with coal, owing to high ash loss and lower fuel-bed temperature. A thinner fuel bed must be used, as a high draft pressure has a tendency to blow holes in the fire. With mixtures of coal and 25 to 40% coke breeze, continuous loads of 200% have been carried and 300% peaks, even with a ratio of heating surface to grate surface of over 50 It is desirable, where possible, to remove the fines, or dust, under $\frac{3}{16}$ to $\frac{3}{8}$-in. mesh, from breeze used for steam fuel.

Burning Lignite.—Lignite, or brown coal, is characterized by high volatile matter and hydrogen, and by high moisture capacity, both as to natural content and absorption on exposure to the weather. The following analyses are typical:

	Arkansas	Alaska Texas	No. Dakota
Moisture	29 73	28.63	27.13
Volatile hydrocarbons	37.87	32.53	29.11
Fixed carbon	23 95	30.43	36.16
Ash	8.45	8 41	7.60

The heat value averages 7000 *BTU* per lb. as received, running up to 10,000 to 13,000 on a moisture-free basis. Lignite has a distinct woody appearance. The high moisture content makes freight charges heavy, and it is difficult to transport or store on account of slacking from evaporation in warm weather. While it has good heating value for its cost, it gives trouble from slow ignition, and from its tendency to splinter or disintegrate on heating, obstructing the passage of air through the fuel bed and making it hard to drop the ashes without losing the small pieces of combustible. The *Bureau of Mines*, after experiments in the regular testing furnace and in a specially designed furnace for burning both natural lignite and the carbonized gas-plant residue, recommends for **hand firing** a furnace as in Fig. A, page 381. It has an inclosed step-grate and an arch extending from the bridge wall over almost the entire length of the grate. The fuel is fed from a magazine by gravity alone or a pusher plate, and the grate contains horizontal air spaces, which are easily kept open by the poker or by rocking, but which do not permit coal to drop through. The ash and clinker are removed by the side cleaning door or by dumping. The high ignition temperature required by lignite cannot be supplied by an arch depending on radiation, but the long arch shown supplies heat by convection from the gases from fuel already burning. This arch does not reach a temperature over 2000° F. with natural lignite, and tiles suspended from water tubes could be used, as in locomotive furnaces, in burning residue. The greater part of the air is admitted at the ends of the gate, encountering lower

resistance than that coming through the grate, and inducing a scrubbing action tending to gasify the fuel. These air openings are not exposed to fusing Very little air is admitted at the magazine, as the fuel is merely dried at the top of the grate. The rate of distillation with lignite is very uniform compared with other forms of coal, the gases consisting mainly of CO and hydrogen, which are easily burned within a short travel, with little danger of producing smoke. The primary CO_2 formed is reduced in the fuel bed to CO, so that with low rates of combustion the bed is almost black. The gases are thoroughly mixed in the opening between the front and rear arch, and are consumed in the space above, where the sudden checking of velocity causes the fluffy ash to deposit The same idea can be applied to a chain grate, with an adjustable gate to regulate the fuel bed thickness While lignites produce clinker and require high draft when burned on horizontal grates, they are easily burned with the furnace recommended, especially in the form of carbonized residue, which, owing to its uniform size, flows readily down the grate, and would even be suitable for household use They can also be burned powdered or in briquettes, or used in gas production

The burning of lignite on ordinary grates is difficult Steam recommends a large combustion space and states that the best results are obtained with a reverberatory furnace, giving long travel to the gases. The fuel bed can be 4 to 6 in thick, and the fuel should be fired in small quantities by the alternate method Above certain rates clinker forms rapidly. Considerable draft should be available, but should be carefully regulated by a damper. Smokelessness with hand firing is practically impossible. There is a strong tendency to foul the heating surfaces, which should be cleaned frequently Shaking grates assist in cleaning the fire, but considerable fuel may pass through
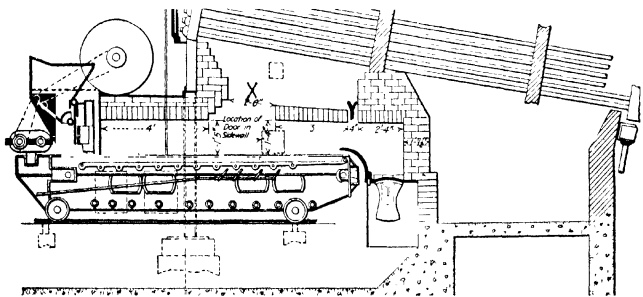
C   CHAIN GRATE FURNACE FOR LIGNITE —*Power.*

J. F. *McCall* has used the arrangement shown in Fig C, for burning high-moisture coal on chain grates. A deflection arch extending over the entire grate except at the point X serves to roll the flame forward and ignite and dry the entering fuel. The small opening Y at the rear creates a draft, which burns out the residual carbon. With a 335 HP. boiler he was able to burn Alberta coal containing 15% moisture, 12% ash, and 30% volatile, with an equivalent evaporation of 8 lb.

A. HAND-FIRED FURNACE FOR LIGNITE

—*Bureau of Mines.*

B   CHAIN-GRATE FURNACE FOR BURNING LIGNITE
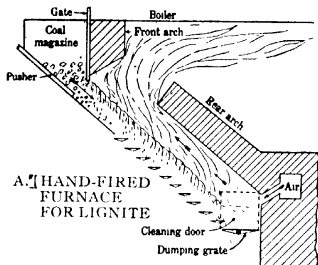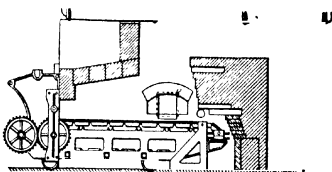
—*Power.*

T. A. Marsh describes a chain-grate furnace designed for lignites from Alberta, Canada, containing 30% moisture. It has a liberal igniting arch and a rear arch for directing the heat and gases forward to dry the incoming fuel, as shown in illustration in Figure B. *C. E. Cope* states, however, that in a number of power plants using Alberta lignite the best results have been secured with the short arch nearer the coal hopper, and the long ignition arch extending forward toward the short arch. He states that this brings the heat farther forward, and dries and ignites lignite slack which they had formerly been unable to use on chain grates.

Marsh also describes the installation shown in Fig. D, used for burning Colorado lignite containing 23% moisture, 12.4% ash, 8865 *BTU* per lb. 72% efficiency was secured in daily operation at 273% rating when burning 60.9 lb. coal per sq. ft. grate per hr. A long ignition arch (10 ft. horizontal dimension) is used, induced draft is employed, with air-tight setting at gate and hopper, while pre-heated air is taken at 80° F. from the turbine room. In spite of the moisture in the coal, it is tempered with 5% water before it goes to the crusher, where it is reduced to 1¼ in. screenings. Fig. E shows

D   SETTING FOR COLORADO LIGNITE

—*Power Plant Engg.*

a setting used with Texas lignite, with a reversed arch from the bridge wall, bringing the heat forward over the fuel bed, in addition to the ignition arch. This gave efficiencies of 69 to 71% with lignites averaging 7000 *BTU* per lb. Fig. F represents an "L" type coking chain grate, with an inclined coking plate at the front, approximately 3 ft. long, on which the incoming fuel is dried and ignited. The efficiencies obtained in settings of the various types illustrated are notable when it is considered that the heat to evaporate and superheat a moisture content of 30% represents 5% of the total heat of the fuel as fired.
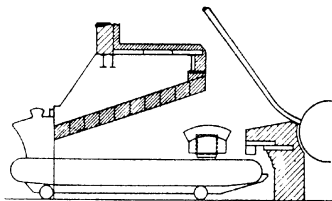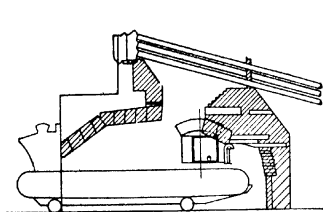
E   SETTING FOR TEXAS LIGNITE
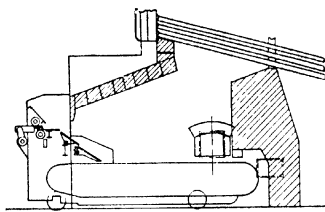
F. "L" TYPE COKING CHAIN
    GRATE—*Power Plant Engg.*
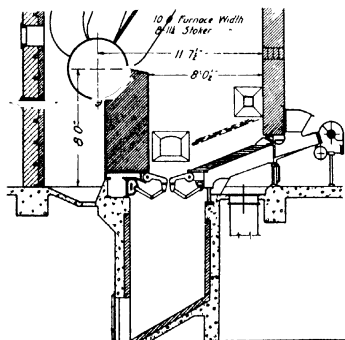
G. FURNACE FOR MIXED LIGNITE
    AND BITUMINOUS—*Power Plant
    Engg.*
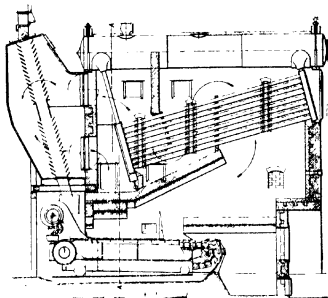
H   SETTING FOR PRE-DRYING
    BROWN COAL.—*London Engg.*

Albert Canfield states that the multiple-retort underfeed-stoker shown in Fig. G, while too small to take care of the 400 HP. boiler at full rating when using lignite alone, gave good results with a mixture of lignite and Eastern bituminous. The latter ignites rapidly and assists in the drying and disintegration of the lignite, and its coking action holds the lighter lignite in position, even with high under-grate air pressure. With lignite containing 7000 *BTU* and 30% moisture, and costing 46% as much per ton as Western Pennsylvania screenings of 12,750 *BTU* content as fired, it was found most economical to use a mixture containing 62% lignite by weight, which gave 5½ lb. equivalent evaporation per lb. of coal, when operating at 120% of rating, at a fuel saving of 12% compared with using bituminous.

Fig. H illustrates an Underfeed Stoker Co. Chain Grate installation in which flue gases are passed through the feeding chute, containing two parallel inverted louvre sides, to dry the moisture in the brown coal.
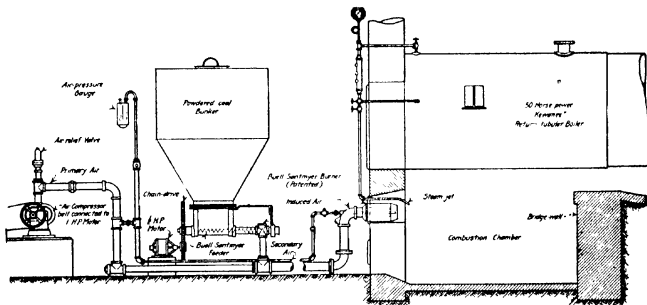
I. EQUIPMENT FOR BURNING PULVERIZED LIGNITE
—*Coal Age.*

Roy N. Buell describes an experimental plant, see Fig. I, in which California lignite of high ash and moisture was successfully burned in a pulverized condition The fuel contained 22% moisture, 43% volatile, 20% fixed carbon, and 14% ash, with 9322 *BTU* per lb. as received. This was crushed to ½ in. size and dried to 6% moisture, consuming 2½% of the fuel, pulverized to 175 mesh, and fed under 12 oz. pressure, 60% of the air for combustion being obtained by induction. The average equivalent evaporation obtained was 9 lb. per lb. of dry fuel, with 14.5% CO_2. No trouble was experienced in storing the pulverized lignite.

Work by the *Bureau of Mines* at Grand Forks, North Dakota, shows that it is feasible to convert lignite into a "char" in an oven resembling an open-top lime kiln. The combustion zone is maintained by burning some of the distilled gases within the moving mass of lignite, and less than 5% of the weight of the original lignite is burned, the fixed-carbon loss being less than if separate driers were used. The combustion gases escape through the upper zone, driving off moisture. About 2½ tons of raw lignite reduce to a ton of char, of an analysis similar to that of anthracite, but softer and more readily ignited, and containing slightly more volatile matter, with a heating value of 12,000 *BTU* per lb. The size is from pea down, the moisture is low, and the char can be stored without danger of fire or degradation in size While raw American lignites cannot be briquetted without a binder, lignite char can be shipped loose or briquetted.

W. A. Bone states that by heating brown coals and lignites to a temperature around 600 or 700° F., water and CO_2 are driven off, with traces of CO and hydrocarbons, and with the loss of only 8 to 15% of the coal substance. This affords a practical method of up-grading the fuel by heat treatment.

C. C. Osbon states that machine-cut peat can be used in practically the same way as bituminous coal, having high oxygen and low ash content, and being equal in heating value to some grades of mine-run coal. The manufacture of peat briquettes by drying, adding a binder and compressing would be of doubtful economic value in this country, but if peat is macerated and compressed without a binder, while containing about

35% moisture, and then further air-dried, a hard briquette is obtained at low cost. Peat is also adapted for conversion into powdered fuel, for stationary or locomotive use, and for the manufacture of producer gas and of coke. Ordinary peat coke is equal to good wood charcoal, while that from well-macerated, thoroughly-decomposed, low-ash peat is hard and comparable with coke made from coal.

John B. C. Kershaw describes the inclined or stepped grate used extensively in Europe with internally-fired types of boilers, for all kinds of low-grade fuels, as lignite, peat, tanbark, sawdust, siftings, etc. Some of these are of the usual form with straight bars while the type shown in Fig. J has plates arranged like a staircase with "risers" omitted for admission of primary air. The combustible gases are burned with the aid of secondary air, which enters through an adjustable damper below the hopper and passes back and then up through cavities in the side wall, this method serving to preheat the air and cool the walls
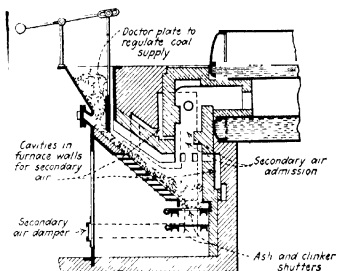
J   STEP GRATE FOR LOW-GRADE FUEL
—Elec. World
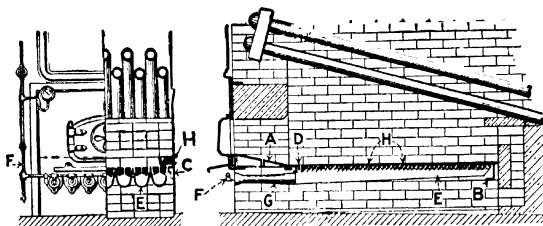
"TURBINE" FURNACE APPLIED TO WATER-TUBE BOILER—Power

The "Turbine" type of grate has been used successfully in England for burning low-grade fuels, even in very small sizes. The setting illustrated has seven troughs E supported front and back, and loosely in contact with each other, each trough carrying 40 to 50 fire-box castings H, V-shaped from the side, locking together, with ⅛-in. air slots between. Steam is taken from the top of the boiler, reduced in pressure and superheated by passing through a tube in the side flue and distributed to steam jets in front of each trough, from which it passes through Venturi tubes G. The steam draws in air, which is uniformly distributed under the fire-bars, due to the diminishing cross-section of the troughs. Ash and clinker are

removed by raking out over the dead-plate *A*, and small amounts of dust falling through to the troughs are removed by a long-handled scoop. The apparatus is easily installed in existing boilers; tests under Galloway boilers, 28 ft. long by 7½ ft. diameter, with economizer and 120-ft. chimney, showed an equivalent evaporation of 6 lb per lb of coal, using Midland slack of 9076 *BTU*, as against 4 34 lb per lb of coal with ordinary fire-bars

Hogged Fuel.—Wood refuse, on account of its high oxygen content, is capable of producing, with zero excess air, over 20% CO_2 by volume. *H. W. Beecher* gives the following calculated flue-gas analyses, based on the dry-wood analysis on page 110, and states that with a step-grate furnace and 20 to 30% excess air, 15 to 16% CO_2 should be obtained

FLUE GAS ANALYSIS FROM COMBUSTION OF HOG FUEL

	0	20	40	60	80	100
CO_2	20 37	16 96	14 53	12 71	11 29	10 16
O_2	0 00	3 50	5 98	7 85	9 31	10 46
N_2	79 63	79 54	79 49	79 44	79 40	79 38
	100 00	100 00	100 00	100 00	100 00	100.00

Excess Air, %

The number of lb of air is approximately 7 65 for each 10,000 *BTU*, irrespective of the ratio of carbon to hydrogen

Originally wood refuse was fed through openings on the two sides of the shell of return tubular boilers, immediately in back of the front wall, resulting in piling against the side walls, with chilled fires and low capacity. With Dutch ovens the fuel, fed through openings in the arch, forms piles on the grate, with longer gas travel and a portion of the green fuel shielded by brickwork from direct radiation to the cool boiler surface. A drop nose or curtain wall located at the inboard end of the furnace arch serves further to shield the green fuel bed from boiler tubes, provides additional incandescent surface for reflecting heat onto the fuel pile and issuing gases, and directs the gases downward into the combustion space beyond the bridge wall, preventing short circuit toward the tube surface.

Fig 1 shows a sloping-grate furnace designed by *Beecher*, used with either standard grate bars or "step grates," in which the fuel is fed across the entire face of furnace and drops down over the grate area in a blanket of more or less uniform thickness. The ordinary method of burning fuel in conical piles on flat horizontal grates means that the central portion of the fire is too thick and the outside edges too thin for the most economical results. It also makes necessary the supplying of most of the air required for combustion by the overdraft method, due to the greater portion of the fuel on the grates being burned on the surface of the cone In the step-grate furnace the upper portion of the fuel bed forms a distillation zone in which the volatiles and moisture content are rapidly driven off. The lower portion of the fuel bed is a mass of incandescent carbon through which the air is readily drawn, due to its open or porous nature. The process of combustion approximately consists of the uniting of air with the incandescent carbon to form the CO_2, which in turn, in passing through the remaining portion of the fuel bed, takes up carbon, to be reconverted into CO. Secondary air is admitted through tuyeres *T* in the bridgewall and unites with the CO as it leaves the incandescent fuel bed to be reconverted to CO_2. This secondary air also unites with the volatile gases driven from the upper portion of the fuel bed and the furnace becomes in effect a
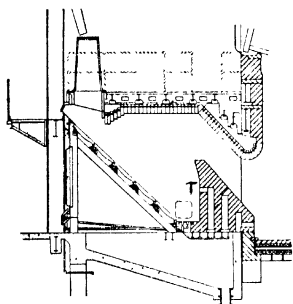
1. SLOPING GRATE FURNACE WITH
STANDARD GRATE BARS
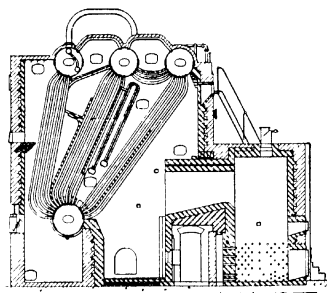
2. HEARTH-TYPE FURNACE FOR
HOG FUEL AND OIL
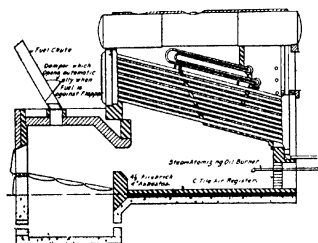
3. HOGGED-FUEL FURNACE, PORT-
LAND EL. PR. CO.
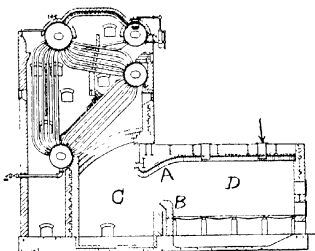
4. DUTCH-OVEN SETTING, BENT-
TUBE BOILER
—A.S.M.E.

combination of a gas producer and a gas-burning retort. The drop nose on the inboard end of furnace deflects these burning gases downward, allowing long gas travel before they reach the tube surface and insuring complete mixing and combustion of the gases. With properly designed step grates there is no riddling of cinders or fuel into the ashpit. The slag which forms on the grate can be removed by a slice bar between the grate openings with the plant in operation. The dump grates can then be utilized to clear the furnace of slag. The fuel forms a seal in the hopper across the face of the furnace, preventing the admission of excess air. The secondary air supply can be separately regulated to correspond with the rate of combustion desired. Fig. 2 shows the hearth-type furnace, which is grateless, with special combustion chambers and mechanical oil burners for supplementing hog fuel with oil. It is equipped with forced-draft fans and ducts and is used at high rating, the slag being drawn off through the clean-out door at the bottom of the furnace.

Claire C. Simeral gives the following heat balance taken at the Portland, Oregon, Electric Power Co., on a furnace of the type shown in Fig. 3. The fuel-bed thickness is maintained at 18 in. at the bridge wall, tapering down to a "feather edge" at the furnace front. Steel-plate induced-draft fans are used, driven by Corliss engines, the speed of which is controlled by the steam pressure at the main throttle. A regulator of this type, controlling the draft for one-third of the boilers in the station, increased the plant capacity 10% under base-load conditions and 25% for emergency calls. Cinders are removed by cindervane fans or, more effectively, by cyclone dust precipitators, and sluiced to the ash dump. The grates are of the common rib-bar type with ⅝-in. air openings, and must be cleaned after the consumption of one unit per sq. ft. of grate surface, as the sand and silt in the bark fuse with the wood ash.

HEAT BALANCE, STATION L, PORTLAND ELECTRIC POWER COMPANY HOG FUEL BOILER

Percentage of rated capacity ...	49.2	104	150	202	260	298
Efficiency based on fuel as fired, %	65 0	65 6	64 6	63 0	62.9	58.1
Efficiency based on dry fuel, %..	58 7	58 2	58 0	56 9	56.7	52.6
Loss due to heat carried away in dry flue gases, %	8 5	10 1	11.3	12 7	13 5	16.5
Loss due to evaporation of moisture in fuel, %	10 1	11 5	11 1	10 7	10 7	10.7
Loss due to heat carried away by steam formed by the burning of hydrogen, %	7.6	7 8	7.9	8 3	8.5	8.9
Loss due to unconsumed hydrogen and hydrocarbons and unaccounted for, %.	5 7	5 6	5 2	6 4	5 9	6 2
Loss due to radiation, %	8 3	6 0	5 4	4 0	3.1	2.5
Loss due to heating moisture in air, %	0 3	0 2	0 5	0 8	1 2	1 7
Loss due to CO, %	0 8	0.6	0 6	0 2	0 4	0.9
Total, %	100 0	100 0	100 0	100 0	100 0	100.0
Moisture content, %	41 8	45.0	43 8	41 9	41 1	40.3
Heating value of 1 lb dry fuel, BTU	8890	8798	8971	8751	8675	8557
Heating value of 1 lb of fuel, as fired, BTU	4669	4288	4519	4587	4612	4630
Flue temperature, ° F	465	471	525	560	595	660

C. L. Young describes some Dutch oven settings as developed by sawmill operators for their own use. Fig. 4 shows a 750-HP. Kidwell watertube boiler, with 1 sq. ft. grate area per 2 7 rated boiler HP., for wet redwood containing 60% moisture. The Dutch oven proper, *D*, may be considered as a retort for the destructive distillation of the wood, and has a party-wall (not shown) dividing it into two parts, each 8 ft. 9 in. wide, reflecting heat into the fuel bed. The 2-ft. nose on the flat arch *A* aids in igniting the combustible gases and particles, and deflects them down into the combustion chamber *C* behind the hollow bridge wall *B*, from which secondary air is jetted through ducts at about 12-in. centers. This setting gives a long flame travel with complete combustion before the gases strike the boiler tubes. A 450-HP. Stirling boiler was equipped with 1 sq. ft. grate per 3.1 rated boiler HP., using the same general construction as this, with a flat arch under the mud drum and oil burners in the rear wall. Wet hemlock chips are burned, mixed with a little planer dust and shav-
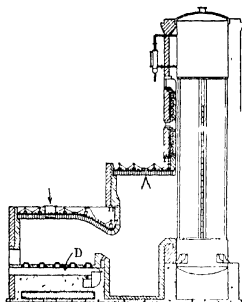
5. DUTCH-OVEN SETTING,
   VERTICAL BOILER
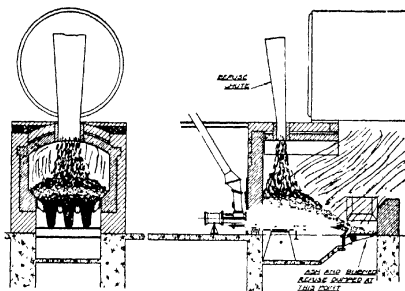
7. UNDERFEED STOKER USED FOR BURN-
   ING HOGGED FEED—*Power House*
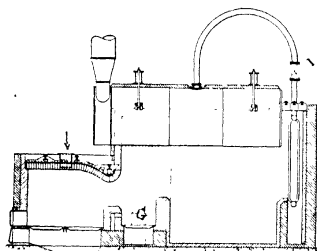
6. DUTCH OVEN SETTING, H. R. T
   BOILER—*A.S.M.E.*
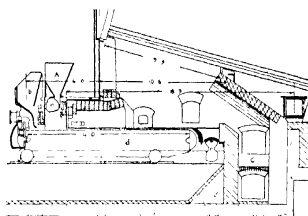
8 FURNACE FOR MILL REFUSE
   AND COAL—*Power Plant Engg.*

ings. Fig. 5 shows a 300-HP. Wickes vertical water-tube boiler equipped with an *A. I. Thomas* grateless furnace, with a second arch *A* above the Dutch oven to provide combustion space in front of the tubes. Air is forced into the ducts *D* set in solid masonry covered with a brick floor, and escapes through renewable cast iron nozzles. Fig. 6 shows an ideal setting for a 72-in. x 18-ft. horizontal return-tubular boiler, with a secondary air grate *G* for burning such solids as blow over the bridge wall.

Beecher states that furnace temperatures with hog fuel are usually below 1600° F., and that 2300° F. is 'seldom exceeded, but that the ash contains more or less lime from stones, salt from salt water, calcium carbonate from teredo borings, and iron oxide. The calcium and iron flux with the oxides of aluminum and silicon, causing glazing and running of the furnace linings. Local abrasions occur along the side walls and around the feed holes.

R. L. Beers describes a self-cleaning underfeed stoker, Fig. 7, used for burning hog feed, with a feed hole through the top of the extension

furnace, supplied with a continuous stream from a conveyor, while coal is fed from the front, through three retorts. When burning 246 lb. of coal and 2550 lb. of hog feed per retort per hr, it was possible to operate the boilers at 177% of rating. For boilers under 300 HP., hand-cleaned stokers can be used.

F. Johnstone-Taylor describes the chain-grate setting for burning mill refuse shown in Fig. 8, with which an evaporation of 3 to 3½ lb. of water per lb. of refuse was obtained. The grate surface is 80 sq. ft., boiler heating surface 3900 sq. ft, furnace width 9 ft. A wood hopper *A* and coal hopper *b* are used, with a small supplementary rear furnace *C* for the consumption of heavy pieces of wood.
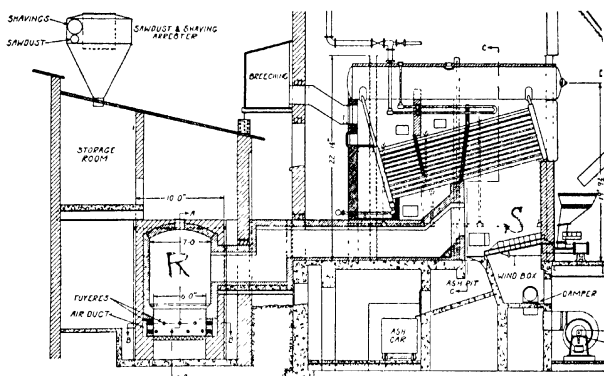
9.   REFUSE BURNER AND UNDERFEED STOKER—*Power Plant Engg.*

C. W. Smith describes a system of burning wood refuse in connection with a 400 HP. boiler, Fig. 9, with Jones A-C coal stoker *S*. The refuse burner *R* is located in a building outside the boiler room, and is equipped with 30 tuyeres placed in rows 6 and 12 in. above the grates, emitting air from a small blower at 1-in. static pressure The burner space is 12 ft. high, and the gases pass through a brick tunnel with rectangular turns to the stoker bridge wall. The ash-pit and fire doors are opened only when necessary, and alternate layers of sawdust and wet bark are fed from above. 435 HP. is developed when burning wet refuse alone, and over 1300 HP. with refuse and coal, the usual draft carried being 0.3 in. in the boiler combustion chamber and 0.6 in. at the breeching damper. A fan is used when burning large amounts of refuse or wet bark only.

Fig. 10 shows a step-grate furnace with underground smoke flues, used in Hawaii for burning **bagasse**. Dutch-oven furnaces with heights of 8 to 11 ft. from top of grates to crown of semi-circular arch are much used there.
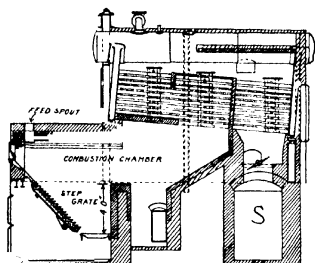
10. BAGASSE FURNACE—*Power Plant Engg.*

11. BAGASSE FURNACE

12. TANBARK FURNACE

13. CHESTNUT-CHIP FURNACE
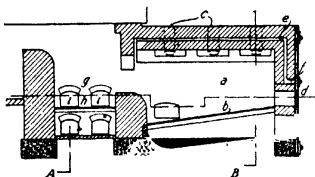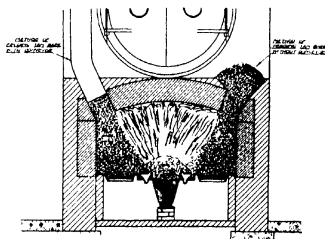
14. UNDERFEED STOKER FOR BURN-ING TANBARK—*Power House*
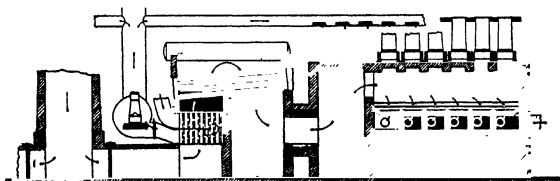
15. FURNACE FOR BURNING CITY REFUSE

Fig. 11 shows a bagasse furnace with extra-large combustion chamber, special baffle walls, and automatic feed hoppers which by means of engine- or motor-driven rolls stoke the bagasse through the hole H in the furnace roof. The duct D under the furnace supplies air to the horseshoe-shaped furnace tuyeres B and to the combustion-space tuyeres C, the auxiliary oil burners E being used in emergencies. Tests on a furnace similar to this, except for the use of grates in the furnace chamber, showed an equivalent evaporation of 2 46 lb water per lb. of bagasse containing 42% moisture, when operating the 500 HP. boiler at 160% of rating. E. W. Kerr has devised a drier in which the bagasse falls over a series of inclined shelves placed opposite each other, the gases being drawn through the chamber by a fan. All kinds of boilers are used, including Scotch Marine, while the furnaces are of the Dutch oven or the Abel type, the latter hav- ing very large combustion chambers Bagasse has been burned at high rates of combustion, up to 200 to 300 lb. per sq. ft. of grate per hour, corresponding to 12 to 20 B.H.P. per sq ft. Tests by Kerr show boiler efficiencies of 50 to 70%. It has also been burned in conjunction with oil, causing a hotter fire than can be had from either fuel alone.

Fig. 12, by David M. Myers, shows a furnace adapted for firing a 150 HP. boiler with either tanbark or coal. The bark-burning furnace is in front, with stationary grates b, and six eyes c for feeding bark; behind this there is a coal furnace with side-doors and shaking and dumping grates h. The duct e furnishes an auxiliary supply of combustion air and protects the arches. When bark only is to be used for a period, the coal doors are sealed, and the bark holes are fired alternately with intervals of 5 to 15 minutes between firings, with a fuel bed just deep enough to prevent blow holes When the bark must be supplemented, fine coal or slack can be mixed with it before firing, or the coal can be fired at d, no bark being fed through the front holes For straight coal firing, the bark furnace is isolated In plants where bark only is to be burned, Myers recommends a V-shaped overfeed stoker, in which the draft currents are directed to a focus of combustion in the central zone of the furnace, like the flames of an acetylene burner.

Fig. 13 shows a furnace designed by David M. Myers for burning chestnut-extract chips, which contain as much moisture (65%) as tan- bark and have smaller heating value. A sloping grate is used, adjustable to feed fuel as rapidly as consumed, while the auxiliary air supply enters through the top of the furnace front, is heated in the duct e, and is directed into the combustion zone by the suspension arches A fan blower supplies air below the grate, while the furnace is "landlocked," each point within it being exposed to hot brick, thus maintaining high furnace tem- perature. When using chestnut chips only, containing 3132 BTU per lb. as fired, 64% efficiency was obtained, and 52 6% with a mixture contain- ing 30% of dry chips, shavings and bark from a paper mill.

Fig. 15 shows a Heenan-Froude refuse destructor in which a mixture of garbage and dry city refuse is burned with the production of useful heat. A large combustion chamber is used, and the air supply is delivered under pressure below the grates, being preheated by passing through the white-hot clinker. A mixture containing 46% garbage, 21% fine ash, 8% coal and cinders, and the remainder "rubbish," gave an equivalent evapora- tion of 1.31 lb. of net useful steam for power purposes per lb. of refuse.

BURNING POWDERED COAL

Powdered coal offers the practical possibility of combustion with only a small excess over the amount of air theoretically required, and with the minimum loss of combustible in the ash and flue gases. The kind of fuel or rate of driving can be changed quickly to meet varying needs, and fire room labor is reduced. It becomes possible to purchase coal on the basis of price per BTU, as the other characteristics of the fuel have comparatively little influence on its utilization. The method, however, calls for elaborate equipment for preparing the fuel, and requires special furnace design in which provision is made for proper combustion with minimum depreciation of the brickwork. *A. L. Cole* states that the total consumption of pulverized coal for all purposes in this country in 1924 was more than 20,000,000 tons, or double what it was in 1920.

N. C. Harrison gives the following data as to the **cost per ton of drying and pulverizing coal** at the plant of the Atlantic Steel Co., during January and February, 1919.

	Tons per day		
	80	90	100
Labor, 48 hrs. daily at 365 = $17 60.............	$ 22	$.195	$.176
Repairs, based on $1002 47 for 2 mos., for 5275 tons	.19	.19	.19
Power, 17.9 kw. hrs. per ton, at ¾ct..............	.134	.134	.134
Drier coal, 8 7 lb required per ton of coal originally containing 2.62% moisture, at $5 per ton......	0218	.0218	.0218
Total cost per ton handled	$ 5658	$ 5408	$ 5218

F. A. Scheffler and *H. G. Barnhurst* summarize the cost of delivering pulverized coal to boilers as follows:

	1,000-Ton Plant per Net Ton	100-Ton Plant per Net Ton
Power at ¾ cts. per kw. hr. and 17 kw. hr. per net ton.	$0.1275	$0.1275
Labor at 40 cents per hour...........................	.14	.04
Drier coal at $5 per net ton delivered................	.06	.06
Repairs	.07	.07
Total actual cost of pulverizing.................	$0 3975	$0 2975
Interest at 6%.......................................	.105	.039
Depreciation, bldg. 40 yr, driers 15 yr, balance 20 yr..	.12	.04
Taxes and insurance, 2%.............................	.035	.013
Total cost	$0.6575	$0 3895

A. E. Douglas presented the following average of costs in a number of modern plants, at the World Power Conference, July, 1924:

Capacity, tons per day	100	150	200	400	500	1000
Cost per ton, bit. coal......................	$.45	.41	.40	.36	.34	.315
Cost per ton, anth. or high-ash coal........	.63	.55	.53	.40	.45	.43

These costs do not include fixed charges such as interest and depreciation on the equipment, but do include labor, repairs, operating materials, power and supervision.

H. D. Savage states that while investment and labor costs may differ with plants, the power consumption in kw. hr. per ton of coal will average: Mills 12.5, Conveyors 1.0, Driers 2.7, Fans 3.0, Feeders 0.8, Total 20.0.

He gives the following data on a 3000 HP. plant for the month of January, 1920:

Cost per Month

Unloading (cars to track hopper), about 50% of cars were of bottom dump type, balance had no dump and coal had to be shovelled over side into track hoppers....	622 hrs. at	40c.—	$248.80
Mill operator (day)	208	"	60c.	124.80
" " helper (day)...................	208	"	40c.	83.20
" " (nights)	208	"	50c.	104.00
" " helper (nights).....	208	"	40c.	83 20
Power consumed by pulverizing mills.....	55,440 kw.-hr. at 1c.			554.40
" " " drier.....	315	" " "	31.50
" " " elevator, conveyor and coal feeding equipment.......	10,450	" " "	104.50
Coal used in drier furnace	26 8 tons at $4 80			128.60
Lubricant, oil at 46c. per gal, grease at 10c per lb				47.25
Coal burned during month.. .. .. 3,150 tons				
Labor costs per ton pulverized..				$.20
Power " " "		. .. .		.22
Miscellaneous " " " (drier coal and lubricant)....... ..				.05

Total cost of labor, power and miscellaneous items for unloading, drying, pulverizing, and conveying pulverized coal from car to boiler-furnace exclusive of overhead   ..   .   . . $.47

The fire-room cost for the same month was as follows, bringing the total operating cost per ton up to $71

Firemen	720 hr at 51c.	$367.20
Boiler washer and cleaner	416	"	40c.	166.40
Repair man (acting foreman of washer and cleaner)	208	"	60c	124 80
Ash handler	208	"	40c	83 20

At the Lakeside, Milwaukee, plant, the cost per thousand lb. equivalent evaporation, adjusted to a labor rate of 75c per man-hour, a coal cost of 22c per million *BTU*, and a boiler rating of 175%, and including maintenance of boiler- and pulverizing-room buildings, fixtures and grounds, coal for banking, and all expenses from car dumper to ash dump was in 1923 Operating labor, $ 023; maintenance labor, $.010; maintenance material, $ 009; supplies and expenses, $ 001; lubrication, $.001; fuel for steam, $ 244, grand total, $ 288

The net energy cost of pulverization was 11% in 1924, and that of conveying and pumping coal before and after pulverization was almost negligible, while net energy cost of drying was 0 16%   See pages 397 and 421.

Edwin B. Ricketts presented the following summary of his study of the factors affecting the choice of a combustion system, at the 1923 convention of the Stoker Manufacturers Association:

In Favor of Stokers.

1. $1.00 to $5.00 per kw. lower first cost of plant.

5. The cinder problem on stokers has been solved and while experimental work looking to the solution of this problem for powdered coal

is being actively pushed with every promise of ultimate success, a definite solution is still in the future.

6. In some plants, stoker ashes can be disposed of to better advantage.
8. Stoker plants require 15 to 25% less labor and 12 to 20% less auxiliary power.
9. Cost of repairs equal.
11. No explosion hazard with stokers; there is a slight hazard with powdered coal.

In Favor of Powdered Coal.

2. Operating efficiency with coal of constant quality $2\frac{1}{2}$ to $4\frac{1}{2}\%$ better.
3. Daily and hourly fluctuations in coal quality do not affect capacity and efficiency to as great an extent with powdered coal as with stokers.
4. Powdered coal will give reasonably good efficiency and capacity with all types of coal. If an unsuitable coal is used on a stoker it may result in losses of very considerable magnitude.
7. Saving of from 1 to 3% of the total fuel is probably due to a reduction in stand-by losses.
9. Cost of repairs equal.
10. Less outages for repairs to furnace equipment are indicated.
12. There is no question about the ability of powdered coal furnaces to use highly preheated air to advantage; with stokers this question is still to be determined.

Coals Suitable for Pulverizing.—*Herington* says that the greater the volatile combustible content, the more readily will the powdered coal ignite and burn, and the less dependent will be the process upon the size and proportions of the combustion chamber. As the volatile content decreases, more dependence must be placed upon the proportions and location of the surrounding brick work in order to maintain the temperature for ignition. Even anthracite has been burned in a pulverized form. It must be very finely ground and burned in a rather confined space, so that the ignition will be prompt and aided by nearby brick work. *N. C. Harrison* reports that the coals giving the most satisfactory results are those with less than 10% ash, of high melting point, volatile 30 to 40%, fixed carbon 40 to 50%, and sulphur not over 5%, preferably much lower. The softer grades, which are also high in volatile, are more easily pulverized, and slack and screenings are the preferable sizes, although uniformity in quality is important.

A. L. Agnew gives as the average analysis for coals for pulverizing:

Volatile matter 39%
Fixed carbon 53%
Ash 8%
BTU per lb............................ 13600
Sulphur 2%

Preparation. The unit system is used for small installations; in it the fuel for each individual boiler is prepared as needed, in apparatus located immediately in front of the boiler, without provision for drying or for storage.

In larger plants, a multiple-type is generally used, which may include rotary car dumpers, breakers, driers, pulverizing mills, conveyors and feeders; and even if individual apparatus is applied to each boiler, cross-connections prevent interruption of service due to breakdowns.

J. G. Coutant states that the unit system of burning undried pulverized coal represents 1¼ to 2% economy over the use of storage methods and driers, considering power and coal consumption, loss of coal dust entrained with the gases from the drier, low-temperature oxidation, etc. Modern types of unit pulverizers equipped with improved means of air separation employ only 30% of the air with the fuel, and as they grind by attrition rather than by crushing, they are not subject to cushioning effect and increased power consumption with high moisture in the coal. The pulverizer preferably receives heated air at 350° to 400° F, and with the heat generated in the mill tends to feed the moisture in the coal to the furnace in the form of dry steam

Drying.—*C G Spencer*, of *McClellan & Junkersfeld*, engineers on the Cleveland installation, summarizes the following advantages to be gained by a low and uniform moisture content in the coal entering the mills:

(a) Increased boiler efficiency due to less coal being required to evaporate and superheat this moisture into steam to be lost with the flue gases.

(b) Greater mill capacity; it being not unusual to observe a 25% reduction in mill capacity due to an increase of from 2 to 4% in moisture.

(c) A reduction in mill capacity due to moisture is accompanied by an increase in the kilowatt-hours per ton for milling

(d) Lack of uniformity in dryness has been observed to require a 30% change in feeder speed to maintain a constant evaporation, other conditions remaining the same

(e) The tendency to arch in bins is reduced as the moisture content is reduced.

(f) Low moisture content reduces the tendency in cold weather for condensation to collect and form a paste throughout the milling, conveying and storage system

(g) Improved furnace conditions due to more constant rate of coal feed and improved combustion because less heat is absorbed by the evaporation of excess moisture at the point where it is most needed.

R. D. DeWolf states that the experience of the Rochester Gas and Electric Corporation was that there is no necessity of drying when the moisture is under 4 or 5%, while *J. B. Johnson* found that this amount of moisture was necessary to prevent flooding through feed screws. *H. G. Barnhurst* ascribes the successful use of undried coal containing up to 7% moisture at Milwaukee to the fact that much of it is inherent moisture, and he believes that the best results are secured when the surface or free moisture is below 2%

Christie states that coal may be dried by three different methods. It may be furnished from some outside source with sufficient heat to raise its temperature to the point where its water content will vaporize, force itself out to the surface of the lumps, and separate out as steam. This process is used in certain rotary driers. A second process is to pass heated gases through the coal and evaporate its moisture content by humidifying the gas. The controlling factor in this method is the wet-bulb temperature to which the coal is heated while evaporation takes place, and not the dew-point as some have stated. This plan is used in the waste-heat driers and steam driers now in use. The third method is a combination of the two previous methods and is employed in the standard rotary drier. The outer shell is heated by the fire and by the hot gases, which afterward pass through the driers, evaporating moisture according to the second method.

The first method is used generally for drying substances that cannot be allowed to come in contact with flue gases, and is not recommended for coal. The third method involves large space, creates a dust nuisance and consumes considerable fuel, but affords thoroughly-dried coal which· can be pulverized in screen mills with less power than in air-separation mills. With the second method, undiluted hot flue gases are now used, as the oxygen content is too low to start fires and the coal remains at wet-bulb temperature, practically throughout its whole passage through the drier. Such driers are useful for removing surface moisture.

HEAT REQUIRED AND COAL BURNED PER 100 POUNDS OF COAL CONTAINING 2% MOISTURE ON LEAVING DRIER.—*Blizard*

		4	6	8	10	12	14
Moisture in coal entering drier......%		4	6	8	10	12	14
Moisture evaporated from coal	pounds	2 1	4 3	6 5	8 9	11 4	13 9
Heat to evaporate moisture from coal	*BTU*	2,300	4 700	7 200	9,900	12,600	15,500
Heat given to 100 pounds coal . .	*BTU*	4 100	4 100	4,100	4,100	4 100	4,100
Total	*BTU*	6,400	8 800	11,300	14 000	16 700	19,600
Coal burned in drier at 70% efficiency..Lb		0 68	0 95	1 25	1 58	1 93	2 32
60% efficiency .Lb ·		79	1 11	1 46	1 84	2 26	2 71
50% efficiency .Lb		95	1 34	1 76	2 21	2 76	3.25

The heat required to evaporate 1 lb of moisture equals $1080 + 0.48T - t$, where t is initial temperature of coal to be dried, and T is temperature of exit gases The table is based on drying with 14,000 *BTU* coal, $t = 70°$ F., $T = 200°$ F., specific heat of coal $= 0.24$, dried coal leaving at 240° F. Whether the firing is with pulverized or solid fuel, considerable excess air is required to keep the gas temperature down. *Blizard* states that it is better to use a drier that is too large than one too small, as the small drier may overheat the coal, causing ignition or loss of volatile and subsequent condensation of steam in bins, etc The elevator or conveyor removing the dried coal should be interlocked electrically with the drier, to prevent detention of coal therein

The *Bureau of Mines* tests at the *Lakeside* station showed that to prepare 1 ton of dried pulverized coal required about 20 lb. coal and 1.5 kw. hr. to operate the drier, and 12 to 14 kw. hr. for pulverizing, representing a total of say 42 lb. per ton (2 1% of the coal), or 1 8% considering reduced heat losses in the furnace. With undried coal, the pulverization power increased to 18 kw. hr., or 27 lb. coal, per ton, which is 1.3%. With undried coal the capacity of a 6-ton mill may be reduced to 4 5 tons per hr. It seems necessary to remove only the surface moisture or "wetness" of the coal, so that it does not stick together or cling to the surfaces of the pulverizing mill, conveyors or feeders. *Kreisinger* states that in general coals from the Appalachian and Eastern coal fields may be pulverized and burned without drying, while Illinois and Western coals must be at least partly dried. The trend in design is toward a small drier that will dry coal to a sufficient extent as it moves toward the mill. Such driers are built in the form of an enlarged coal chute, supplied with waste gases or exhaust steam, and remove from 2 to 4% moisture, while preheating the coal, so that it loses moisture readily in the mill. At *Cahokia* flue gases enter the driers at from 300 to 400° F., and leave at 150 to 200° F., raising the coal to 175° F. and removing 2% moisture, while 6% moisture escapes from the mill vent, out of an original total of say 12%. About 3 lb. of gas is used per lb. of coal, or about one-quarter of the total flue gases. Where the preparation room is too remote, or where the gases are cooled in an economizer, a drier may be used with coal passages made of steam-heated grids, about 1 lb. of air per lb. of coal passing through the coal.

Drewry reported in 1925 that the average amount of coal used for drying at Lakeside, *per 1% of moisture removed*, was 2 lb. in summer and 5 lb. in winter. The table below gives the average coal-drying figures for the month ending November 10, 1924:

Total coal dried, tons	22.818
Coal used for drying, tons	57
Lb. of coal used per ton	5 00
Moisture of coal, drier inlet, %	4 54
Moisture of coal, drier outlet, %	2 82
Moisture removed, %	1.72
Lb of coal used per ton dried per 1% of moisture removed	2 90

This represents 0 25% of the total coal flow. Assuming 30% drier efficiency and allowing for the heat which would be necessary to evaporate this moisture in the furnace, the net energy cost of the coal-drying process was 0.16%. The average moisture content at the bins was 1.77%, showing about 1% of moisture disappeared during pulverization

Tests by the *Bureau of Mines* at Riverminnes, Missouri, on a *Raymond mill* and *Ruggles-Cole drier* are given below. With the dried coal 25% more can be pulverized per hr., at 25% less power consumption It seems that only surface moisture need be removed in the drier to enable the coal to be pulverized easily. The undried coal burns without difficulty; the net overall gain by not drying, considering fuel and power consumption of both machines, was 0 7%.

SUMMARY OF RESULTS OF PULVERIZING MILL TESTS

		Dried.	Undried.
Condition of coal			
Capacity	tons per mill-hour	5 6	4.2
Power required per ton	kw hr	13 9	18 5
Moisture in coal as pulverized	%	4 9	6.1
Coal through 100-mesh screen	"	94 9	95.0
Coal through 200-mesh screen	"	75 0	76.0

SUMMARY OF RESULTS OF DRIER TESTS

Capacity per hour	tons	15.62
Moisture content before drying	%	7.53
Moisture content after drying	"	4 87
Power required per ton of coal	kw. hr	1.68
Coal used in drying, % of coal dried		1.29
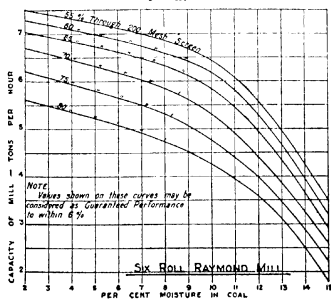
H. D. Savage gives 3% as the upper limit for moisture of coal to be ground in screen-type mills, while the accompanying curves show the reduction in capacity of air-type mills with coals containing over 5% moisture.
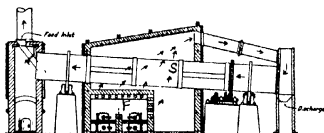
EFFECT OF MOISTURE ON MILL   FULLER-LEHIGH DRIER
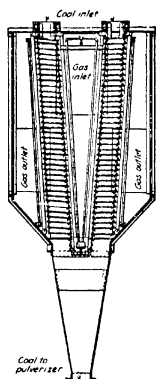
WOOD WASTE-HEAT
DRIER—*Power*
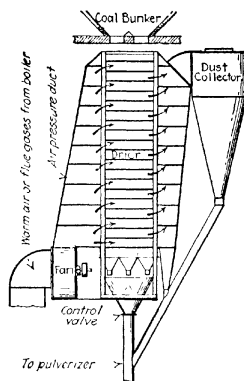
RANDOLPH WASTE-HEAT
DRIER—*Power*
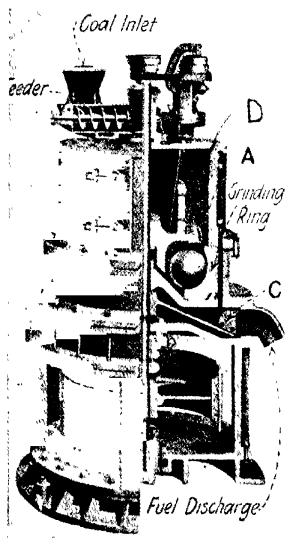
FULLER-LEHIGH SCREEN-TYPE MILL
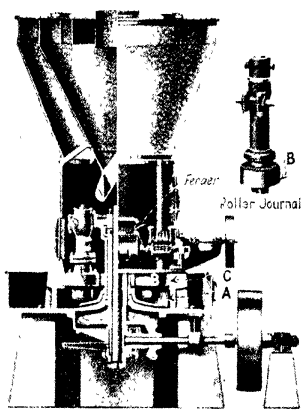
RAYMOND PULVERIZING MILL—
Power

In the *Fuller-Lehigh Indirectly-Fired Rotary Drier*, gases from furnace *F* (fired with solid or powdered coal) pass up around the long revolving shell *S*, then to the right and back through the inside of the shell, through which the lump coal flows from left to right. In the *Grindle Multiple-Tube Rotary Drier* the coal passes by gravity through a number of tubes on the outside of a revolving cylinder, while the gases flow first along the outside of the tubes and return through them. The *Wood Drier* receives flue gases from the boiler at the top center and discharges them below, the coal descending through two louvered passages. The steam pipes are used to extinguish any fires which may start. The *Randolph Waste-Heat Drier* is built of unit sections, alternate units having discharge or entrance ports for the gases
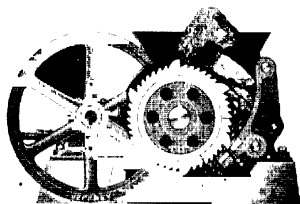
SINGLE-ROLL CRUSHER

A *Bradford breaker* serves to reduce the bulk of the coal to 1¼ in lump, the oversize tailings going to a regular single- or double-roll crusher. The *K-B Pulver-burner* includes a lump-coal storage bin, an automatic belt feeder with adjustment for varying rate of feed, swing hammers revolving at 900 rpm. and striking on a breaker block, the position of which is adjusted by bolt *A* to allow for wear, and a fan for drawing off the fine coal and delivering it to the burners.

Pulverizing.—From the crushers and driers the coal is fed to air-separation or screening pulverizers. In the *Fuller-Lehigh Screen-Type Mill* the coal is fed from above, and is ground by four unattached steel balls rolling in a grinding ring. The fine coal is lifted by the fan *A*, passes out through the cylindrical screen *D*, and is pulled down and discharged by a second fan *C*, the fans being on the same shaft with the
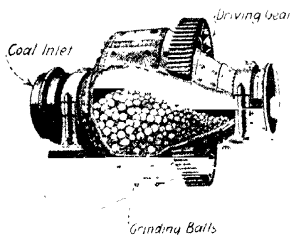
HARDINGE CONICAL BALL-MILL
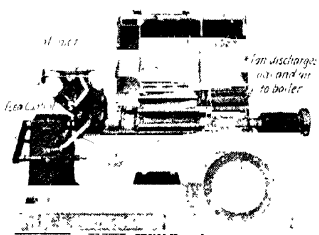
UNIT-TYPE PULVERIZER—*Power*
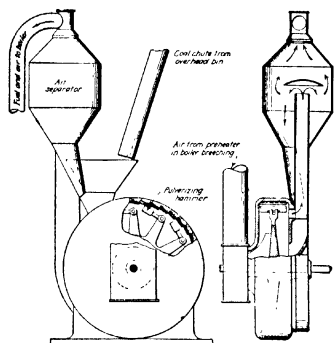
BETTINGTON UNIT-TYPE
PULVERIZER—*Power*
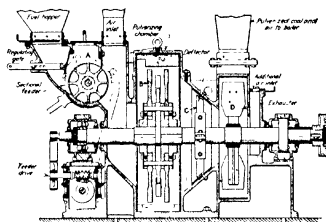
RAYMOND IMPACT UNIT-TYPE
PULVERIZER—*Power*
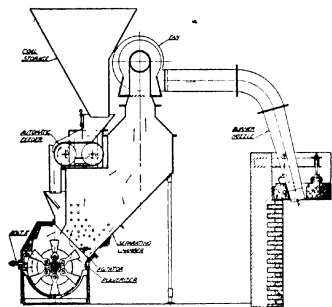
K-B UNIT TYPE PULVERIZER—*Power*
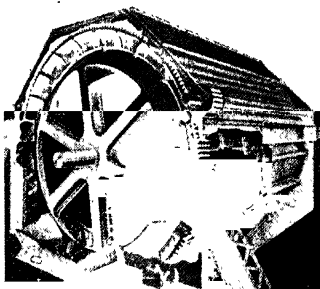
BRADFORD BREAKER REDUCES
LUMP COAL TO PROPER SIZE
FOR PULVERIZING—*Power*

pushers which drive the balls around. Coal not passing the screen falls
back for further grinding. In their air-separation type there is a separa-
tion chamber above the grinding balls, in which the powder automatically
separates, the finest particles rising and being carried off by the exhaust
fan while the coarser sink and are reground. The *Raymond Mill* employs
rollers *B* mounted on vertical shafts which rotate around a central verti-
cal shaft. The coal is agitated by the rotating plows *A* and by air from the
ports in *C*, is ground between the rollers and the grinding ring, and
ascends to the separator and collector. Horizontal rollers are employed
in the *Bonnot Mill*, acting in a concave grinding ring, and the coal is
separated in a compartment having adjustable deflectors. In the *Hardinge
Ball Mill*, the coal is rolled around with steel balls in a conical container,
and in other types of mill a series of rings are loosely mounted on a

shaft, interspersed with stationary blades. The *Aero, Erie City* and *Fuller-Lehigh Unit-Type Pulverizers* contain paddles mounted on one cylinder and revolving within another, and the pulverizing is aided by the masses of coal sliding on each other. In the *Bettington and the Raymond Impact Pulverizers*, hinged hammers are rotated, beating on the inside of cylindrical shells.
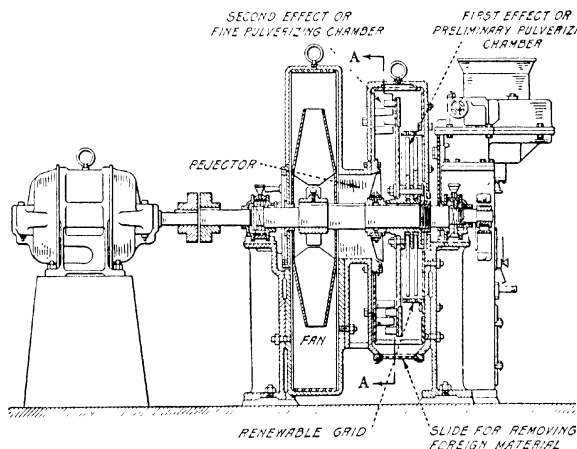
A. RILEY UNIT PULVERIZER—*A S.M E.*

R. Sanford Riley and *Ollison Craig* describe the development of a "unit" pulverizer and drier, Fig. A, in which the first effect contains swing hammers revolving within a grid of which one section is omitted, while the second effect contains two rows of renewable hard-composition cast-iron pegs alternating with two rows which revolve with the disk separating the two effects. The swing hammers perform the coarse pulverizing, and throw out any tramp metal through the grid opening, while attrition is effected in the second chamber, from which the fine product is withdrawn by the fan. When pulverizing 4000 lb. per hr., the power required at the shaft is 9.2 kw. hr. per ton, and 13.6 kw. hr. per ton for 1500 lb. per hr. With Eastern bituminous coal having 7% moisture an average fineness of 90% through 200-mesh is obtained, with all but a trace passing 50-mesh screen and a large proportion of extreme fines. Capacity tests with Eastern bituminous coal having 3% to 5% moisture showed 6750 lb. pulverized per hr., to a fineness of 81% through 200-mesh, with 2.6% remaining on a 50-mesh screen, using 6.7 kw. hr. per ton.

L. V. Andrews classifies coal pulverizers as follows: *Contact mills*, in which the coal is ground in a thin sheet or ribbon between two elements which have a rolling action with respect to each other, and which consist

of a circular bull ring as one element, within which are revolving balls or rollers comprising the second element. The two elements are forced together by the action of centrifugal force or powerful springs, thus crushing any material which is introduced between them. *Tube and ball mills* employ as grinding members either tubes, rods, or balls, or combinations of these, forming one element, contained in a horizontal revolving cylinder which comprises the second element. Pulverization is accomplished by the tumbling action of these tubes, rods, or balls when the cylinder is set in motion, and takes place between the members comprising the first element as well as between these and the shell of the revolving cylinder. *Impact mills* include the new types of unit pulverizers employing as primary grinding elements high-speed paddles, pegs, or hammers which shatter the coal particles by striking them at high speed or by hurling the particles violently against each other or against stationary liners, corrugations, or pegs, which may be considered as secondary elements. *Attrition mills* are machines employing a rubbing action between the grinding surfaces. In *non-contact roll mills* pulverizing is done by passing a ribbon of coal between rolls which crush it as in a flour mill.

A. L. Cole states that for bituminous coal of high volatile content, a fineness of 65 to 70% through a 200-mesh screen is now generally considered satisfactory, but for anthracite coals 95% should go through 100-mesh and 85% through 200-mesh. As the power consumption increases rapidly with the fineness of pulverizing, the effects of changes should be carefully checked for a particular fuel. The dimensions of standard screens are as follows:

TESTING SCREENS OF WIRE MESH CLOTH

Mesh Openings per Linear Inch	Wire Diameter, Inches	Opening Width, Inches	Openings per Square Inch
100	0.0045	0.0055	10,000
200	0.0021	0.0029	40,000
300	0.0016	0.0017	90,000

Andrews calls attention to the fact that the testing of pulverized coal on 100 and 200-mesh screens gives no indication of the character of the fines. He suggests the use of microscopic slides for investigating the distribution of fines, or the plotting of a curve giving amounts through the
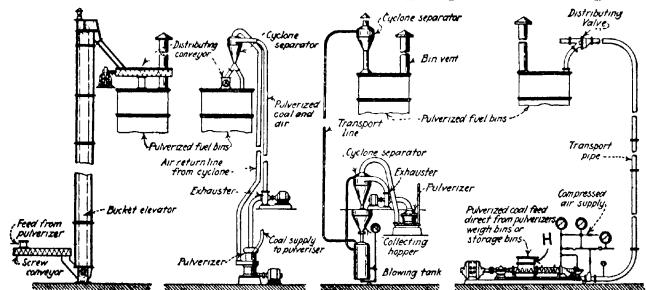
Screw and Bucket   Air Current   Compressed Air   Pump and Compressed Air
TYPICAL CONVEYING SYSTEMS—*Power*

various larger screens, which might give some indication of the fines distribution below 200-mesh.

Conveying.—The distribution system can be direct, as with unit pulverizers and the circulating systems used in connection with metallurgical furnaces, the fuel being blown directly to the furnaces from the grinding room in a current of low-pressure air; or indirect, the coal being conveyed, by screws or compressed air, to bins from which it is fed to the furnace. While the latter requires separate bins and feeders for each furnace, it affords better control of rate of feeding and protection from shutdown and presents less danger from explosion. The four typical arrangements shown in the figure are from *Power*. The left-hand one shows screw conveyors and a bucket elevator leading from the pulverizer to the feeding bins. In the second figure, the exhauster draws a current of fuel and air from the pulverizer, and forces it to the cyclone separator, where it expands and the bulk of the fuel drops to the bin, the cloudy air being returned to the pulverizer. In the third one the fuel from the cyclone and collector attached to the pulverizer passes to a blowing tank equipped with scales, from which it is blown by compressed air to another cyclone mounted on the feeding bin. The right-hand figure shows a system adapted for transporting fuel long distances. Pulverized fuel entering the hopper *H* is started in motion by the screw conveyor, and is aerated at the point of discharge by a number of small streams of compressed air, so that it passes through the transport line as a fluid.

Storage.—Care in the storage of pulverized coal is essential. In itself it does not contain the elements required for combustion. The dust will, however, take fire very easily, a lighted match being enough to ignite it, but in mass it simply smoulders away harmlessly. Damp pulverized coal should never be stored for any length of time, as spontaneous combustion is likely to occur. 96 hr. is a safe limit for dry coal. The hopper should have two sides sloping at about 30° with the vertical. This prevents the coal from arching. It should be free from pockets where the powdered coal will lodge and remain stored for some time. Its capacity should be sufficient for only 12 to 14 hours' use, and it should be covered to prevent the accidental introduction of fire or foreign matter or the absorption of moisture, which is rapid. Coal has been stored, however, for a period of a week or 10 days in pulverized form. It should always be kept moving and not allowed to stand more than one day in case of temporary shut-down.

Feeders and Burners.—In the *Fuller-Lehigh Feeder* the powdered fuel is carried by a feed screw and dropped into a mixing chamber from which the primary air carries it to the fantail vertical or horizontal burners. The tips are hinged and adjustable through a 10° arc so that flame impingement can be prevented, and the secondary air inlet is also adjust-
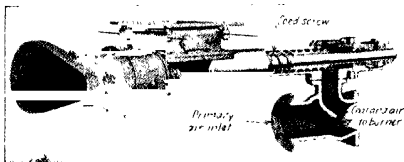
FULLER-LEHIGH FEEDER—*Power*   FULLER-LEHIGH BURNER
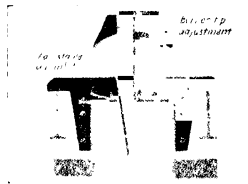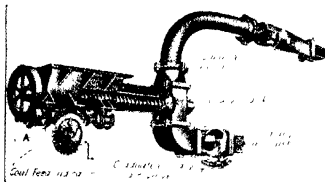
GRINDLE FEEDER
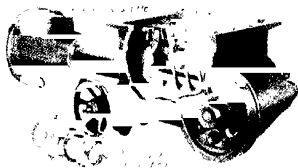
FULLER-QUIGLEY FEEDER

able. *H. G. Barnhurst* states that
the horizontal method of firing
permits a higher combustion rate
per cubic foot of furnace volume,
but is limited to fairly high vola-
tile coals, while the vertical method
will handle a wide range of coals.
The *Lopulco Burner* is described
on page 415. The *Grindle Feeder*
contains an equalizer disk at the
end of the screw, smoothing out
pulsations due to packing, and a
coal and air mixer consisting of
two fans revolving in opposite
directions The *Fuller-Quigley*
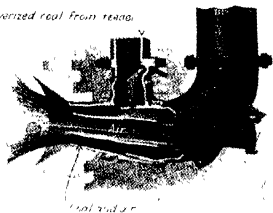
RAYMOND BURNER—*Power*
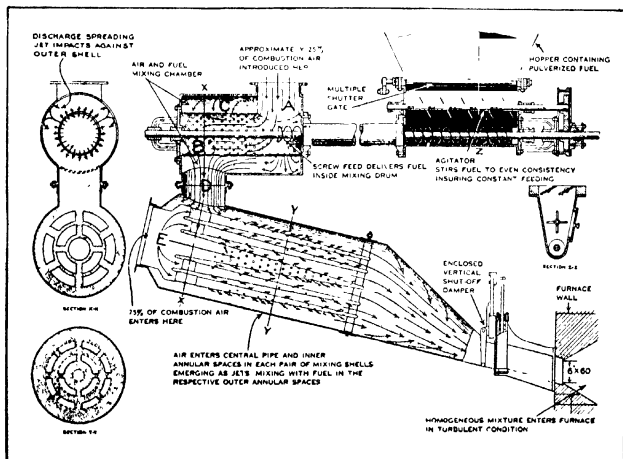
MULTIMIX BURNER

Screw Feed operates at constant speed, and the rate of feed is adjusted by two shutter vanes. In the *Raymond* circular burner powdered fuel mixes with the air in the outer ring of the burner and flows horizontally into the furnace in a hollow cylindrical stream, while the inner tube introduces an additional core of air for combustion.

The Multimix Burner is designed to introduce an intimately-mixed mass of coal and air for its combustion into the furnace at a low velocity, so that smaller furnace volume is required to complete the combustion than with apparatus where the current impinges on an air cushion. The sloping cylindrical chamber *Y-Y* contains a number of concentric annular rings through which a fuel-air mixture flows and takes up additional air from the air rings between them   A 13,000 *BTU* coal requires 8½ lb. of air, so that even with no excess air each particle of coal should be surrounded by 5000 times its volume of air   Coal has been burnt with this burner at a rate of 3¼ lb. per cu. ft combustion space per hr., the refuse containing only 1% of combustible

Furnaces.—*A. L. Cole* states that the best results seem to be obtained at combustion rates of 1 to 1½ lb of coal per hr per cu ft. of combustion space, although satisfactory results are obtained over a range of ½ to 2 lb. The views on page 406 show the settings for several prominent installations. The Lakeside plant has a ratio of sq. ft. of heating surface to cu. ft. of furnace volume of 1 86; this has been reduced in more recent installations, and in the Peoria plant of the Illinois Central Power Co. the ratio is only 0 86   The furnace must of course be of such a shape that the coal may be readily ignited without impinging on the brickwork, and follow a path sufficiently long to permit almost complete combustion before reaching the tubes. The ash naturally fuses, but if it cools as it settles and is kept cool the particles do not stick together and are easily removed   Water screens are often placed near the bottom of the furnace, connected to the boiler circulation, and serve not only to cool the ash but aid in the useful recovery of heat   For "banking," the fuel supply is simply cut off, and the stored radiant heat will keep up steam pressure for a long period with little loss. *P. W. Thompson* estimates the banking loss for boilers operated at 67% load factor at 1.5% for stokers and 0.7% for pulverized coal installations. Hollow-wall furnaces can be used, with the secondary air passing through the side walls from the rear and entering the furnace at the front, at a temperature of 700° F. at the top and 300° F at the bottom. This improves the combustion process, and also reduces radiation losses and increases the life of the refractories. The use of preheat in the primary or conveying air also helps with undried coal, by preventing condensation in the bins. It has been said that 30% of the ash formed in the operation of a pulverized-fuel plant goes up the stack, but *H D. Savage* calls attention to the fact that with 10% ash, this would not exceed 3% of the coal as fired, which was the weight of unconsumed heavy coke cinders emitted by a stoker-fired plant recently tested, and falling within a short radius of the plant. He claims that the emission from a powdered-coal stack is a finely-divided, flocculent, gritless powder, and that if the fuel is ground so that 65% of the particles are smaller than 0 0025 in, and contain 10% ash, the ash particles are only 0 00025 in., and are carried to great distances even by light winds, so that no complaints have arisen even in the heart of business and shopping districts.

Münzinger gives the following table of characteristics of American stokers and pulverized-fuel furnaces:

	Furnace Volume. Cu Ft per Sq. Ft. Boiler Htg. Surface	Lb Coal per Sq. Ft. Grate per Hr.	Lb Steam per Sq. Ft Htg Surface per Hr.	Max. Grate Surface, Sq. Ft.
Underfeed stokers ...... (single end)	.30-.45	60	7-11	440
Forced-draft chain grates	.20- 45	50	7-10	440
Pulverized coal	.60-.95	..	11	...

Lakeside Plant, Milwaukee

Metropolitan Edison Co., Middletown, Pa.

Trenton Channel Plant, Detroit

Providence, R.I.

Eline's Inc., Milwaukee

Cahokia Plant, St. Louis

Unit-type Systems
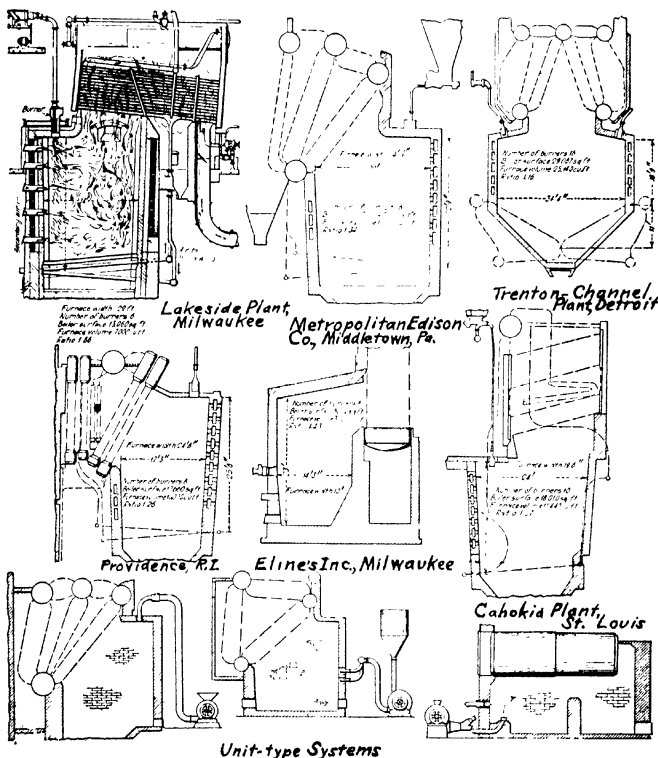
SETTINGS FOR BURNING PULVERIZED COAL—*Power*

Kreisinger states that while powdered-coal furnaces may appear large, the difference in size is not so great when compared with modern stoker furnaces with 20 to 22 ft. between stoker and boiler tubes. It is also true that most of them have been installed under very large boilers to be operated at high ratings, requiring extra large furnaces so that each particle may remain in the combustion space from one to two seconds, and so that the flame will not gouge into the walls. Powdered-coal locomotives have small furnaces, but they are entirely water-cooled, with little or no refractory, and comparatively low efficiency is accepted in competition with hand firing.

A. G. Christie suggests that it is desirable to transfer as much heat as possible by **radiant** energy, and that any influence which tends to lower furnace temperature should, therefore, be closely scrutinized and if possible removed. The entering fuel particles require heat for vaporizing moisture and for distillation, and it is probable that the primary air which accompanies the coal is heated largely from the coal particles suspended in it, which, being black, absorb radiant heat. The length of the pre-ignition flame travel is reduced by having the entering coal as dry and hot as possible and accompanied by highly preheated primary air, although it has not been customary to heat air above 150° F In the flame, the rapidity with which the liberated free carbon particles and the coke cores remaining of the original coal particles combine with oxygen depends very largely on the speed of mixing with heated secondary air. Unless the products of combustion of the volatile gases are swept away from the particles, they remain surrounded by inert gases, hence violent mixing is an essential of rapid combustion and short flames. Liquid ash high in iron oxide combines with silica and alumina of white-hot fire-brick, so that air cooling of brick side walls only becomes effective when the bricks have been washed down to a thickness of ¾ to 2 in., and it is a question whether brick are needed at all in furnace walls. Many engineers believe that brick walls are needed as reflecting surfaces to accelerate the ignition and combustion•of incoming coal and that bare water cooled walls would absorb so much radiant heat that either long flame travel will be necessary or incomplete combustion will result. *Christie* states that only the outer envelope of the furnace flame is affected in this way, and that the net cooling effect will be minimized if the air and fuel are preheated and turbulence exists. In any case the front walls may be of brick, shielding the supporting steel, while air-cooled brick walls or brick-faced water-cooled walls may be necessary to give reverberatory action in furnaces burning anthracite, coke dust, or low-volatile coal. Heat transfer by radiant heat to metal side walls may reach as high as 75,000 *BTU* per sq. ft. per hr., while with brick-lined furnaces the radiant heat is reflected, and although some of it reaches the boiler tubes, much is absorbed by the gases and is later given up by convection in the boiler passes at a relatively lower rate. Completely water-cooled walls, rear and side, should give little trouble from slag or washing, and would permit the development of maximum temperature with minimum excess air and under low-set boilers. A portion of one of the walls might be occupied by a radiant-energy superheater operating either alone or in series with a convection superheater. Gray or calorized tubes would be useful with coke or anthracite, where less cooling by the walls is desired.

Charles Roszak and *Marcel Veron* discuss the claim that the utilization of radiation in pulverized coal furnaces results in flame impingement, and state that this is due rather to sudden overloads on the boiler, to poor water circulation, to insufficient combustion volume, to poor arrangement of tubes and baffles, to cinder deposits, etc. If such impingement does occur, with fire-tube boilers, the direct result of any steps to increase the rate of evaporation is to raise the temperature in the first row of tubes. *Sohm* found that by moving back the bridge wall and the middle baffle the gas temperature at the entrance to the tubes fell more than 350° F. and still more in the first tubes, this being due to the increased transmission by radiation. Thus the tubes divide the load more evenly, which is advantageous at normal operation, and especially so when the boilers are forced. In this way radiation becomes desirable, unless carried to the extent where combustible is lost. Frequent blowing eliminates cinder deposits in the tubes. Screens of water tubes at the bottom of the combustion chamber reduce the radiation to heating surfaces, without lowering the total evaporation, and cool the falling molten globules of ash to solid sand-like particles. Deterioration of brickwork can, to some extent, be laid to radiation, together with the action of cinders *Audibert* says that this is the reason for large combustion chambers; 0 48 cu ft per lb. of fuel per hr. would be sufficient for perfect combustion, but a minimum of 0 64 is used to prolong the life of the walls, reducing the heat imparted per unit of brick surface and the temperature within the furnace.

Walter J. Wohlenberg and *Donald G Morrow* state that the radiating power through the flame surface in a pulverized-fuel furnace depends primarily on the size of the particle, and that based on the flame-surface area its magnitude relative to black radiation is low   The heat-absorption intensity at the cold surface may be considerably higher than the relative radiance of the flame, depending on the amount and location of the refractory furnace lining. They give the following table for coal particles of 0.002 in. diameter, Illinois coal pulverized 75% through 200-mesh, burned with 20% excess air, in a cubical furnace 20 x 20 x 20 ft, with flame 19 x 19 x 19 ft.

Energy Liberation, BTU per Cu Ft per Hr.	Arrangement of Exposed Surface	Approx. Mean Flame Temp °F	Approx. Mean Refractory Temp °F.	U_1	U_2	U_3	U_4
20,000	A	2555	2275	0 36	0 84	0 77	0 30
"	B	2320	1890	0 38	0 68	0 66	0 37
"	C	2270	1925	0 38	0 49	0 50	0.39
"	D	2150	1580	0 40	0 48	0 48	0 43
"	E	2060	.	0 41	0 38	0 40	0 45
15,000	A	2420	2165	0 37	0 85	0 78	0 34
"	B	2185	1790	0 39	0 69	0 67	0 41
"	C	2120	1810	0 40	0 51	0 51	0 43
"	D	2010	1475	0 41	0 49	0 49	0 46
"	E	1920	....	0 41	0 37	0 41	0.49
10,000	A	2225	1990	0.39	0.87	0.81	0.40
"	B	1980	1630	0.41	0.72	0.70	0.46
"	C	1915	1645	0.42	0 53	0.54	0.48
"	D	1810	1340	0 43	0.50	0.52	0:51
"	E	1730	....	0 44	0.40	0.43	0.54

$U_1 =$ relative radiance—radiation intensity of the flame surface compared with that of a black body.

$U_2 =$ radiation efficiency of furnace, a measure of the radiant and reflected energy which actually strikes the cold surface as compared with that which would strike it with a perfect black fuel immediately in front of it It does not include heat absorption by convection at cold surface and does not correct for the reflection from the cold surface

$U_3 =$ relative absorption, total heat absorption at the cold surface compared to that which would result from radiation alone in a furnace with a black fuel bed immediately in front of the black tubes

$U_4 =$ furnace absorption efficiency, fraction of liberated energy which is absorbed in the furnace.

Arrangement A Cold surface at the top face only, which forms the aperture for the escaping gases

Arrangement B Cold surface at the top and bottom faces, the aperture for the escaping gases being at the top.

Arrangement C One half of the interior surface as cold surface, distributed so that one half of the top, bottom, and two sides, and total furnace back is cold surface.

Arrangement D Top, bottom, and two opposite sides as cold surface

Arrangement E Furnace totally enclosed by cold surface.

Arrangement C contains considerable more cold surface than B but the flame temperature of C is only slightly lower than that of B, and, contrary to expectations, the refractory temperature of C is actually higher than that of B. The result is only a slightly greater heat absorption by C (compare values of U_4) for a considerably increased cold surface. This condition exists because in C the cold surface "sees" other cold surface through a much greater solid angle than it does in B Likewise the refractory "sees" other refractory through a larger solid angle The net heat absorbed from the refractory radiation and reflections by the cold surface is thus considerably less in B in spite of the increased cold surface. Perhaps the most useful data, if correct, yielded by such an investigation are contained in the values of the coefficients U_1, U_2, U_3, and U_4. Their magnitudes are indicative of the effectiveness of both the flame and furnace as a partial means of transferring liberated energy to the water and steam. The relative radiation value of various furnace types and surface arrangements apparently can be evaluated with reasonable accuracy in such terms even if the various temperature magnitudes arrived at do not describe in sufficient detail the actual flame as to temperature dimensions. These coefficients are therefore of use to the designer of heat-absorbing vessels in evaluating the convection zone, as well as in evaluating the furnace conditions.

Fig. 1 gives the variation of relative radiance U_1 with flame size, for the size of particles corresponding to 75% of sample through 200-mesh screen. It does not change much except with small flame volume. As shown in Fig. 2, for a given flame volume, the radiance improves appreciably as the particle is reduced in size.

It is stated that pulverization finer than mean particle size 0.002 in. will probably not increase the rate of *energy liberation*, unless some means are taken to create turbulence, such as a centrifugal discharging jet of high velocity.

The relative *ignition* temperature of coal-dust clouds increases with decreasing percentages extractable by pyridine (from 1823° F. for 39% up to 2021° F. for 21%, according to *British Mine Explosion Committee*), that is, with decrease in the proportion of readily-decomposed constituents. *Taffanel* states that the *inflammability* increases with the volatile content
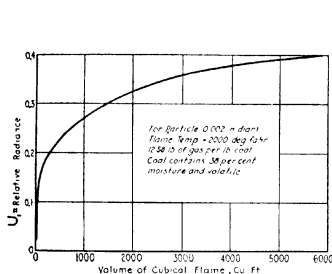
1. VARIATION OF RELATIVE RADI-
   ANCE WITH FLAME SIZE
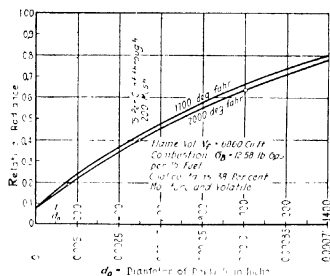
2. VARIATION OF RELATIVE RADI-
   ANCE WITH FLAME-PARTICLE
   SIZE   —A S.M.E.

of the moisture-and-ash-free coal, up to 25%, beyond which it is constant.
The ash and moisture of the coal retard the propagation of flame because
they absorb heat which would be absorbed by the coal substance, and mois-
ture also causes the particles to stick together.

Air circulated in the walls is admitted to the furnace in some other
way than through the burner   While some claim that the quickest com-
bustion is obtained when all the air enters with the coal, *Henry Kreisinger*
states that the inflammability of the mixture is quickest when only 30 to
40% of the air needed is supplied with the coal, and that with anthracite
the admission of all the air with the fuel may cause the flame to puff or
blow out. The accompanying Fig. A gives the speed of flame propagation
for various ratios of air to coal in mixtures, and for different kinds of
coal, as determined by experiments in France on coal-dust explosions.
With most coals the maximum velocity is with a mixture of 2½ to 5 lb.
air per lb. coal. With curve *B*, which is typical of American steaming
coals, a mixture of 4 lb. air to 1 lb of coal can be introduced at a
velocity of 50 ft per sec and the flame will remain steady and near the
burner, but with 7 lb air the flame will be found at a point away from
the burner where the velocity has slowed down to that of flame propaga-
tion for the given mixture   While the chart is for a very fine mixture
issuing into an unheated space, the relations are sensibly the same as for
coarser mixtures entering a furnace, and illustrate the fact that less than
one-half the total air should enter at the burner, and the remainder where
it will have easy access to the ignited flame. If all the air is to be admitted
at the burner, and ignition secured not too far from its mouth, a lower
entering velocity must be used (larger discharge opening). Larger burners
must also be used with reduced volatile or high ash in the coal   For high-
volatile coals the fineness can vary greatly without affecting the inflam-
mability, but fineness increases the rate of propagation in low-volatile or
in high-ash-and-moisture coals.

The work of the *Bureau of Mines* at the *Lakeside Station* showed
that it made little difference what percentage of coal passed through the
100- and 200-mesh screens, if nearly all of it passed through 50-mesh screen.
All particles passing 50-mesh seemed to float in the surface gases, and most
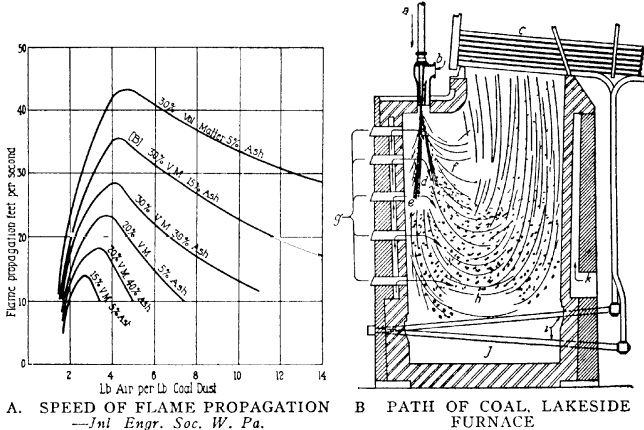
A. SPEED OF FLAME PROPAGATION
—*Jnl Engr. Soc. W. Pa.*

B PATH OF COAL, LAKESIDE
FURNACE

a, Coal and 10% air, *b*, 20% air, *c*, boiler, *d*, velocity 100 to 150 ft , *e*, velocity 10 to 15 ft , *f*, fine coal particles, *g*, about 65% air, *h*, coarse coal particles, *i*, water screen, *j*, ash, *k*, air to hollow walls

larger particles seemed to fall to the bottom, where they smouldered and were removed unconsumed with the refuse. Coal is brought to the six burners by pipes *a*, Fig. B, and with a velocity of about 100 to 150 ft. a second, varying with the rate of combustion, is mixed with about one-tenth of the total air supply needed for combustion. This velocity is greater than the equilibrium velocity of the particles in still air, which will be established first by the smaller particles *f* near the top of the furnace and last by the larger particles *h* near the bottom, where through combustion they are reduced in size The remainder of the air comes down vertically through openings *b* round the burners and horizontally through ports *g* in the front wall. The horizontal velocity of the air *d* and *e* sweeps the particles toward the back of the furnace and will cause the smaller particles to pass to the back with a greater velocity than the larger particles. Finally the flame is carried vertically upward by the draft. Thus in the U-shaped flame the larger particles, which require longer time to burn, move along the under and outer portion, stay longer in the furnace, and have a higher velocity relative to the gases in the furnace. As the coal particles burn they gradually become smaller and their velocity relative to the furnace gases becomes less. Thus, large particles that follow the longer path are nearly equal in size to the smaller particles that take the shorter path by the time all particles reach the upper parts of the rising arm of the U-shaped flame. The size of the furnace must be so proportioned to the maximum rate of combustion that practically all the coal particles have burned to the ash residue *j* by the time they reach the boiler. Any unburned particles of coal that reach the boiler tubes *c* are carried through the boiler and their heat content is not liberated for

generating steam. Coal particles h that are too large never attain their equilibrium velocity and therefore fall to the bottom of the furnace after they have passed through the downward arm of the U-shaped path If the percentage of these very large particles is small, combustion continues after they have reached the bottom of the furnace and they are burned completely. If it is high, they accumulate on the bottom of the furnace, forming a layer so thick that only the top comes in contact with the air, and they become mixed with the refuse and are lost

Wilhelm Nusselt states that the velocity of ignition of pulverized coal varies inversely as the diameter of the particles, and the time for combustion as the square of the diameter. He gives the following calculated values:

Diam. of Particles, In.	Ignition Velocity Ft per Sec.	Combustion Time, Sec
.04	.06	114 0
.02	.13	28.5
.004	.65	1.14
.002	1 29	.284
.0008	3 23	.046
.0004	6 45	.011
.0002	12 9	.0028
.00004	64 5	.00011

The ignition velocities given are based on an ignition temperature of 482° F., combustion temperature 2732° F The ignition velocity increases with the preheat temperature or the combustion temperature, and decreases with the ignition temperature, as shown by the following, for 0 00079-in. diameter particles·

Ignition temp., ° F.	400	500	600	700	800	900	1000	1100	1200
Ig. velocity, ft. per sec	3.5	3 25	3 0	2.75	2 5	2 3	2 1	1.95	1.8

The combustion times given are based on room temperature 68° F., combustion temperature 2732° F, coal requiring theoretically 156 cu. ft. air per lb., at 59° F and atmospheric pressure, but employing considerable excess air. The time required for combustion, as given in the table, should be multiplied by the following factors:

Ratio of actual to theoretical air.	1 1	1 2	1.4	1 6	1 8	2 0	9.0
Multiplying factor	3 58	2 67	2 02	1.75	1 60	1.49	1.07

The *Bureau of Mines* made a series of tests on the pioneer pulverized-coal plant at the *Oneida Street Power Station, Milwaukee.* The boiler used was a standard 468-HP. Edge Moor with three cross-flow passes, with a Foster superheater between the first and second passes, and was old, with leaks around baffles. The furnace, Fig. C, 1430 cu. ft. volume, had been built for an underfeed stoker and contained a front shelf B and a sloping back shown by the dotted line A. Fuel about 10% of the air were admitted through two burners C; the remainder of the air was drawn in by natural draft through ten inlets a in the front wall. When burning about 1800 lb. of Illinois coal per hr., with 50% excess air, the ash became soft and sticky, but did not run, and was removed with some difficulty every 24 hr. When the excess air was reduced, the ash fused and ran like water, and had to be dug out after the furnace was cooled, while the introduction of cooling air through the slag doors caused solid carbon to pass out unconsumed. Slagging was finally prevented by removing the sloping back (increasing the volume to
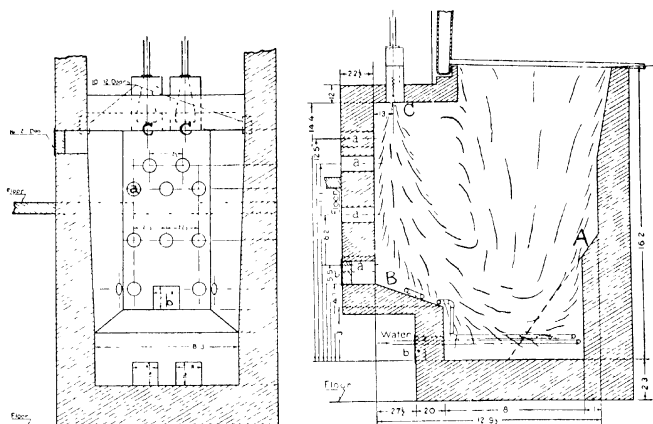
C. ONEIDA ST. PULVERIZED-COAL FURNACE
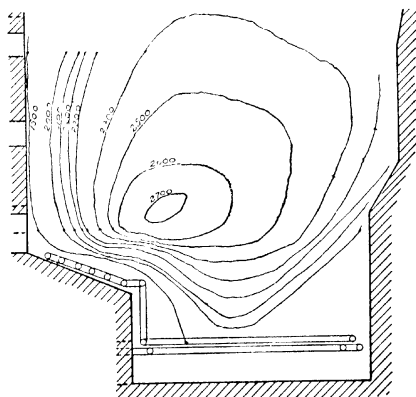
D. ISOTHERMALS WHEN PRODUCING 15% CO_2

1600 cu. ft.) and inserting cooling coils of 2-in. pipe connected to the boiler, in the form of a double row along the sides and back of the furnace base, and three rows across the front shelf. It was found that coal of which only 65% passed through 200-mesh screen gave practically

as good results as 85%, the large pieces falling to the bottom but continuing to burn, and that the use of the coarser fuel increased the pulverizing capacity. Undried coal was found to be satisfactory, both by test and continuous operation, except for the difficulty of lighting fresh fires. Coal containing under 7% moisture was easily handled in the screw conveyors and feeder bins. Round burners were discarded in favor of flat spreading burners, made of steel plate, with openings $\frac{3}{4}$ in. $\times$ 13½ in., which allowed the coal and air to enter in sheet-like planes parallel to the furnace front. Typical temperature curves appear in Fig. D; results when using cooling coil, flat burners and perpendicular back are given in the table below:

Test No.	Overall Efficiency %	Rating %	Coal Lb. per Hr.	Lb. Coal per Cu Ft per Hr.	CO₂ in Flue Gas %	Excess Air %	Flue Gas °F.		
31.. .	82 7	125	1 973	1 23	15 5	17	483	Coarse	Coal
32...	81 0	116	1 862	1 16	15.3	18	457	"	"
33. .	81 7	127	2.024	1 26	15 8	13	472	"	"
34	. 81 9	116	1 882	1 18	15 1	17	470	"	"
35... ...	82.7	112	1 753	1 09	14 6	23	486	"	"
36 .. .	81 7	112	1,866	1.16	15 5	17	484	Undried	Coal
37....	80.4	105	1 785	1 12	15 8	15	466	"	"
38 . ..	80 3	124	2 171	1 36	15 4	17	514	"	"

H. W. Brooks states that the *Bureau of Mines* received advices by municipal smoke inspectors in Milwaukee and Cleveland that careful search had disclosed no appreciable deposition of ash or unburnt carbon from the stacks of pulverized-fuel plants, the ash issuing in the form of a fine dust which becomes highly diluted in the atmosphere. While an electric precipitation method is installed at the Trenton Channel plant of the Detroit Edison Co., it was found to be expensive and probably unnecessary.

J. G. Coutant gives in Fig. E the temperature of gases arriving at boiler tubes, as affecting slag formation on tubes of powdered-coal-fired boilers, and the maximum range of operation of boiler and furnace.
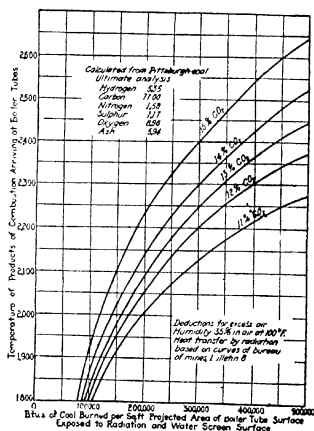
E. APPROXIMATE TEMPERATURES WITH POWDERED COAL—*Power.*

Fig. *A* shows the design of the first eight boilers at the *Lakeside* Station, Milwaukee, each with 13,060 sq. ft. boiler evaporating surface, 286 sq. ft. water-screen evaporating surface, 4023 sq. ft. superheating surface, 7603 sq. ft. economizer surface, and 6073 cu. ft. effective combustion space. Coal from a car dumper is screened in a rotary grizzly, pieces over 2 in. crushed to that size, and the whole reduced to $\frac{1}{2}$ in. in a hammer mill and sent to the pulverizing building. It passes to rotary driers, indirectly fired with pulverized coal, and to ball mills where it is pulverized so that 60% will pass a 200-mesh screen. The mills use air separation without screens, a current of air passing over the bull ring picking up the fine material, which goes to a collector and then to overhead bins in the boiler-house. There are three *Lopulco* feeders per boiler, each with two screw convey- ors *F* (Fig. *B*), 15% of the air used for combustion entering through *J* under 10-in. pressure and being pushed with the fuel by the paddle *K*. The six screw conveyors each lead to a fantail burner (Fig. *C*) in the roof of the furnace, and the 0 05 to 0 2 in. vacuum in the furnace draws in 20 to 25% air through the burner, the amount of this air, which comes directly from the boiler room, being controlled by *B*, while *D* is used to adjust the dampers *E* and hence the distribution of flow and the point below the burner at which ignition takes place. A floating inverted bell in a chamber connected to the furnace controls the steam-turbine-driven fan taking gases from the economizer, and a "Mercoid" master pressure gage governs the speed of the coal feeders, so as to respond to a difference of one lb. from any selected operating pressure, eliminating manual adjustment. The water screen, of 4-in. tubes, prevents the formation of vitreous slag, and takes up about 8% of the heat absorbed. The dots in the chart, Fig. *D*, represent 24-hour tests by the *Bureau of Mines*, in 1923, at various ratings. The high loss at low rating shown in the lower curve was probably due to low excess air with *CO* in the gases; at high rating the loss was due to com- bustible particles carried out by the high velocity.
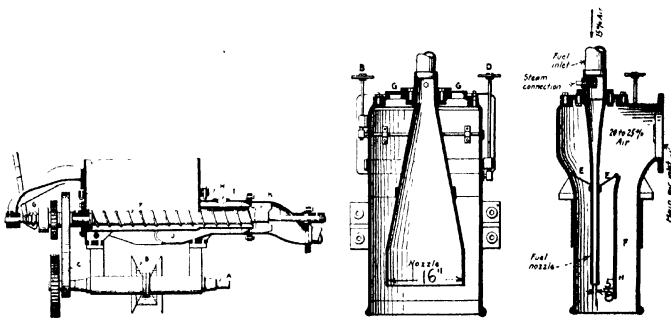
B. PULVERIZED COAL FEEDER.   *C.* PULVERIZED COAL BURNER.—

Power.
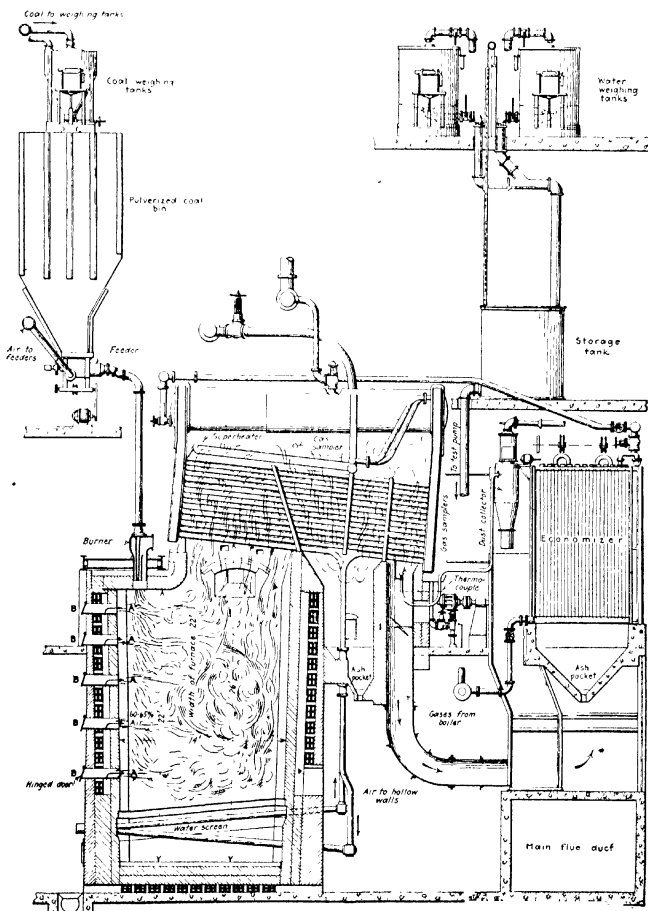
A. ORIGINAL LAKESIDE PULVERIZED-COAL FURNACE.—*Power.*
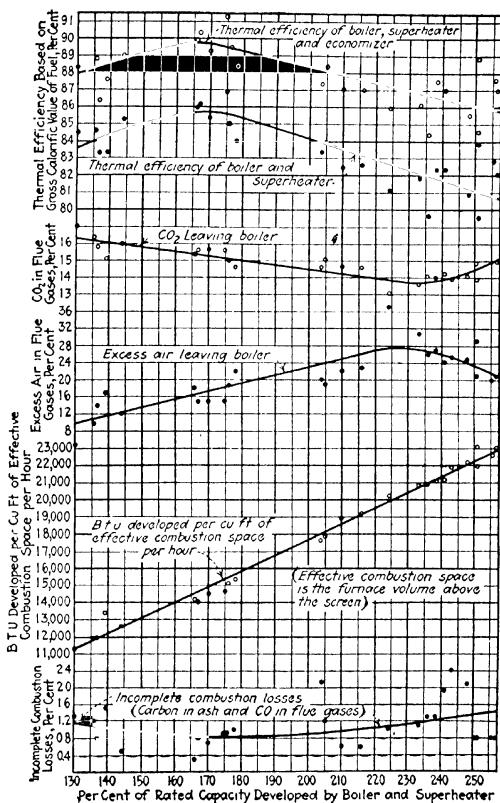
D. 1923 TEST RESULTS AT LAKESIDE PULVERIZED-COAL STATION.—
Power.

The later boilers are shown in Fig. E (p. 422). *M. K. Drewry* reports a study of the station for a month's period of best economy, ending November 10, 1924. The heat balance in Table 1 was made by continuous measurement of the most significant losses. The solids emerging from the stacks during normal operation appeared no darker than pure calcined ash, but 0.5% was allowed to cover carbon losses when starting. Radiation

losses are small. Furnace-casing temperatures average about 110° F., and practically all heat losses contribute, with the supply of heat in the generator cooling air, to maintain the combustion-air temperature at around 100° F. Previous tests on units in the first boiler installation placed radiation and unaccounted-for losses at 2%, but the newer boilers, which carried the bulk of the load during the period considered, have considerably lower radiation losses.

TABLE 1 HEAT BALANCE, LAKESIDE STATION, November, 1924

	BTU	%
Heat per lb. of coal	13,691	100
Heat loss due to moisture in coal	26	0.19
Heat loss due to water from combustion of hydrogen	487	3 55
Heat loss due to moisture in air	10	0 07
Heat loss in dry chimney gases	453	3.31
Heat loss due to incomplete combustion of carbon	68	0.5
Heat loss due to unconsumed hydrogen, hydrocarbons	0	0
Heat radiated but not reclaimed; and unaccounted-for losses	103	0.75
Heat absorbed by boiler, economizer, and superheater	12,544	91.6

The calculated boiler efficiency of 91.6% is modified by the items 2 to 5 in Table 2. The turbo-generator efficiency ratio, Item 2, is a weighted value from tests on the four units used, representing the ratio of the thermal efficiency to the theoretical efficiency of the straight Rankine cycle, and including generator losses and excitation energy. The detailed consumption of energy by auxiliaries is shown on p. 681; 1.1% represented the pulverization, and that of conveying and pumping coal before and after pulverization was almost negligible. The coal drying data are given on p. 397. The value of 2.2% for radiation from the steam piping and turbines was found to give agreement between calculated results and the actual overall economy shown in Item 15. Chief of the unreclaimed radiation losses is the 25° drop in superheated-steam temperature from boiler- to turbine-room. Blow-down losses are only 6 BTU per kw. hr., the character of Lake Michigan water being such that the few dissolved solids settle out at the blow-off pads, and that the concentration of the boiler water is caused to remain continuously very low, less than 0.1° B. The average make-up water for the period was 3.1%, the theoretical requirement being 2.2%, indicating a leakage of 0.9% from the radiant-superheater elements, which has since been stopped.

The most economical efficiency ratio of Item 6 is further modified by Items 7, 8 and 9 to include periods of less economical operation. The decrease in boiler-unit efficiency below that at most economical rating, due to operation throughout the range of loads found in actual practice, was only 0.25%. A banked boiler consumes hourly 2½% of its normal feed at 215% rating, and at 65% load factor for the station, the total loss from banking and starting is less than 2%. To retain heat in a boiler, all air passages to the furnace are closed immediately upon stopping coal feed, and the unit is practically "bottled" tight so that convection losses are a minimum. Under Item 8, uneconomical loading, have been set the weighted losses due to increase of water rate above or below that at the most economical load. It is the practice at the Lakeside station to keep all units, whenever possible, accurately at their most economical loads, these loads

TABLE 2, COMPARISON OF THEORETICAL POSSIBILITIES AND ACTUAL PERFORMANCE

Most Economical Loading %
 1 Boiler efficiency (computed from losses)... .. .. 91 6
 2 Turbo-generator efficiency ratio (from tests). 76.2
 3 Consumption of auxiliaries
    Electrical auxiliaries (from meters)..... .. . . .. 4 25
    Steam (credit given for heat return to condensate, taken from operating data) 1 84
 4 Coal drying (from operating data) 0 25
 5 Radiation and miscellaneous losses 2 2
 6 Efficiency ratio,[1] most economical loading 64 0
Losses Attendant with Actual Operation (Calculated from Operating Data)
 7 Boiler room:
    Uneconomical loading of boilers 0.25
    Banking and starting cold boilers.. . ... 1.98
 8 Turbine room·
    Uneconomical loading 1.75
    Starting 0.26
 9 Unusual operations:
    Entire plant 0 22
10 Total operating losses. 4.49
11 Calculated efficiency ratio, average operating conditions 61.1
12 Theoretical cycle efficiency (Marks and Davis tables).. ... . .. 35.4
13 Calculated plant thermal efficiency... .. .. 21 6
14 Corresponding calculated heat consumption, *BTU* per Kw Hr.. 15,800
15 Actual plant heat consumption..... 15,800

[1]A measure of equipment efficiency Actual boilers, turbines, and auxiliaries have a combined efficiency of 64% of that of perfect equipment Items 3, 4 and 5 are each subtracted from 100, and the continued product of these factors and of Items 1 and 2 gives Item 6.
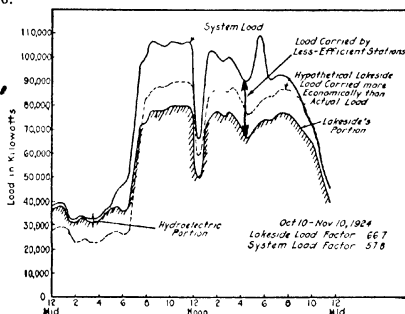
F. LAKESIDE LOAD CURVE.

(System and Lakeside loads on an average day (October 23, 1924). Lakeside load factor from October 10 to November 10 was 66 7: system load factor during same period was 57 8 The dotted lines show a hypothetical load which the station could have carried ½% more efficiently.)

being approximately 95% of the full rated generator capacity in the case of the 30,000-kw. units. The load curve in Fig. *F* shows the greatest throttling loss to occur during the early morning period, 12 to 6 a. m., when approximately 35,000 kw. load was carried by 50,000 kw. capacity. Lakeside's portion of the system load during the period under considera-tion was limited by a shortage of transmission-line capacity. The ratio

of average load to maximum-demand load is of smaller consequence in the economy of Lakeside than is the matter of turbine loading. If the midnight-to-morning load is decreased 10,000 kw. and the day load is increased the same amount (see dotted curve in Fig. F), then banking losses would be increased a maximum of $\frac{1}{4}\%$. Lowering the early morning load for six hours would allow operation of a single 30,000-kw. unit (see Fig. F), effecting a gain of 0.4% of the day's output. The average full load of 75,000 to 80,000 kw. shown in Fig. F was unfortunately above the most economical capacity of the combination of units used (two 30,000-kw. units and one 20,000-kw. unit), and if increased to 90,000 kw., warranting the starting of another unit, it would have netted an additional gain of 0.3% in the turbine room. The sustained economy with which pulverized-fuel boilers carry widely variable loads and the small banking losses explain why load factor has not so important an influence upon economy as has the question of turbine loading. During the period considered the load factor of Lakeside was high, but the turbine loading was uneconomical, causing compensatory effects. Economy results obtained after Lakeside carried the entire system load corroborated the above deductions. Except during peak- and low-load periods, the 30,000-kw. units are kept accurately at their most economical loads by making the overload valve gear inactive. A special handwheel is used for this purpose. In such cases the pressure drop through the primary valve is reduced to 7 lb., and is maintained at that point at all times irrespective of slight changes in frequency. Before studying turbine loading, in many instances units were simultaneously operating above and below their individual most economical loads.

For Item 8, $\frac{3}{4}$-hr. steam consumption is allowed for starting the units. Item 9, unusual operations, covers testing of emergency governors, setting safety valves, etc. The total operating losses, Item 10, are found to reduce the calculated efficiency ratio, for average operating conditions, to 61.1%, which, multiplied by the calculated Rankine cycle efficiency of 35 4% for the steam conditions employed, gives a calculated plant thermal efficiency of 21.6%, equivalent to a calculated heat consumption of 15,800 BTU per kw. hr., corresponding exactly to observed plant heat consumption for the month in question. *Drewry* states that in any modern pulverized fuel station the combination of boilers, turbines and auxiliaries should work at an efficiency ratio of 64%, and that this, multiplied by the theoretical thermal efficiency of the cycle employed and by 95% operating efficiency ratio, should give the approximate ultimate thermal efficiency.

The maximum permissible boiler and economizer air leakage is set at 1.5% decrease in CO_2. This leakage includes infiltration through the economizer bottom, a difficult section to keep tight because of water treatment when washing economizer tubes, although this causes no appreciable thermal loss. Calculation of the standard station efficiency is made each month, and operators are paid 45% of the coal saved above the standard set. This has varied from 8 to 15% of the stipulated wage. Because of the flatness of the boiler efficiency curves and the small banking losses, various boiler loading combinations show little difference in the resulting economy. Maintenance and other considerations determine ratings of individual boilers rather than economy. Table 3 gives operating data with boilers operating at 200% or over. Overall station performance is given in Table 4.

TABLE 3. OPERATING DATA, LAKESIDE PLANT

		Oct. 10 to Nov. 10	1924 Dec.	1925 Jan.	1925 Feb.	1925 March
1	Daily coal consumption, tons*........	867	915	934	825	966
2	Daily output, million kw-hr	1 423	1 528	1 557	1 542	1.629
3	Make-up water, %.......	3 12	3.80	3 19	2.85	2.51
Boiler Room						
4	Rating	213	227	228	228	225
5	Boiler hours, daily......	141 7	136	138 5	136.94	142.4
6	Banked hours, daily....	17	18 1	19 5	19.3	28 63
7	Combustion-air temperature, ° F.....	99	82	84	84	83
8	CO_2, %	14 7	14 8	14 8	14 8	14.7
9	Steam temperature leaving superheater, ° F.	702	687	710	721	717
	Gas Temperatures, ° F.					
10	Economizer inlet	564	572	573	574	568
11	Economizer outlet	232	237	243	244	248
12	Drop in temperature	332	335	330	330	320
	Feedwater Temperatures, ° F.					
13	Economizer outlet	251	248	254	258	260
14	Economizer inlet	119	121	133	137	137
15	Rise in temperature	132	127	121	121	123
Turbine Room						
	Temperatures, ° F.					
16	Throttle, Nos. 1 and 2 units........ .	671	647	640	. . .	619
17	Throttle, No. 3 unit...	682	660	677	683	684
18	Throttle, No. 4 unit	689	658	688	701	695
19	Throttle, No. 5 unit.	.	673	693	702	701
20	Condenser hotwell	73	63	64	63 2	61.8
21	Circulating-water outlet	67	53	56	55.9	54.4
22	Circulating-water inlet	53	38	41	41 1	40 7
23	Circulating-water rise	14	15	15	14.8	13.7
	Pressures, Lb. Gage and In. Hg. Abs.					
24	Throttle, all turbines...	288	286	289	291	293
25	Exhaust Nos 1 and 2 units..	0 91	0 63	0 56	. . .	0.56
26	Exhaust Nos 3 and 4 units	0 94	0 78	0 76	0.76	0.74
Preparation House						
27	% moisture, drier inlet..	4.54	5 58	6 75	7.64	7.18
28	% moisture, drier outlet.....	2 82	2 52	2 48	2 85	2.72
29	% moisture removed	1.72	3 06	4 27	4.79	4.46
30	Tons coal used in drier daily	1.84	6 08	6.96	7.56	8.23
31	Lb. coal used per 1% moisture removed per ton dried	2 90	4.72	3.53	3.41	3.82

*Approximated from daily electrical output. Accurate coal tonnage determined only bi-weekly.

TABLE 4 BOILER AND STATION PERFORMANCE, LAKESIDE PLANT

Month	Plant heat consumption, BTU per kw-hr.	Boiler efficiency, steaming only · %
October, 1924	16,000	89.71
November, 1924	15,945	91.34
December, 1924	16,308	89.67
January, 1925	16,066	88.85
February, 1925	15,861	90.05
March, 1925	15,930	[1]89.7

[1]Reduced due to greater use of oldest equipment.

E. LATER LAKESIDE PULVERIZED-COAL LAYOUT   —A S.M.E.
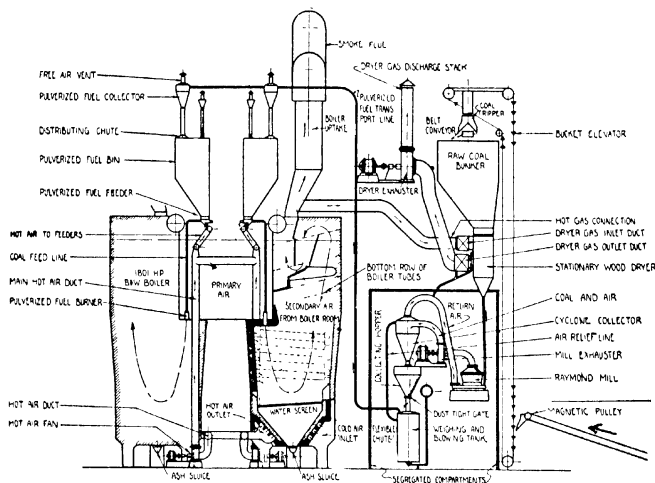
A. CAHOKIA PULVERIZING EQUIPMENT—*Power Plant Engg.*

The *Cahokia, Ill.*, plant of the *Union Electric Light & Power Co.*, *St. Louis, Mo.*, is designed to handle low-grade Belleville (Illinois) coal of 9945 *BTU* per lb, containing 16.69% ash of 2000° F. fusion point, for which it was found that a powdered-coal plant would require 4% less fuel than a chain-grate system, at approximately the same fixed charges, with small banking loss and quick pick-up   The initial installation contains eight B. & W. cross-drum boilers, each 18,010 sq ft., to operate at 200% rating, on natural draft, and 300% if necessary, supplying steam to turbine throttle at 300 lb. and 690° F. temperature. The preparation plant is inside the boiler-house, separated by concrete floor and walls, with light external wall for safety, but the car dumper, with underground Bradford breaker and swing-ring crusher, for reducing the entire coal supply to 1-in. lump, is outside, in the portion to the right of the view in Fig. A. Crushed coal enters the raw coal bunkers and descends to *Wood* driers, where the moisture is reduced from 12% down to 5%, by direct contact with 10 to 12% of the flue gas, obtained from the breeching and withdrawn from the bottom of the drier by fans. Thence it passes to *Raymond* impact pulverizing mills, where it is ground so that 65% passes through 200-mesh, and through a cyclone to a collecting hopper, from which it is periodically discharged to weighing tanks by the operators. After weighing, it is blown to concrete bins, one over each boiler (Fig. A), from which it is fed by *Lopulco* feeders and burners (ten per boiler), the burners being fan-shaped, with a number of nozzles in the bottom. Primary air (15% of the total) is drawn through air ducts in the hopper bottom (Fig. B) by fans under the center aisle and sent to a common duct supplying
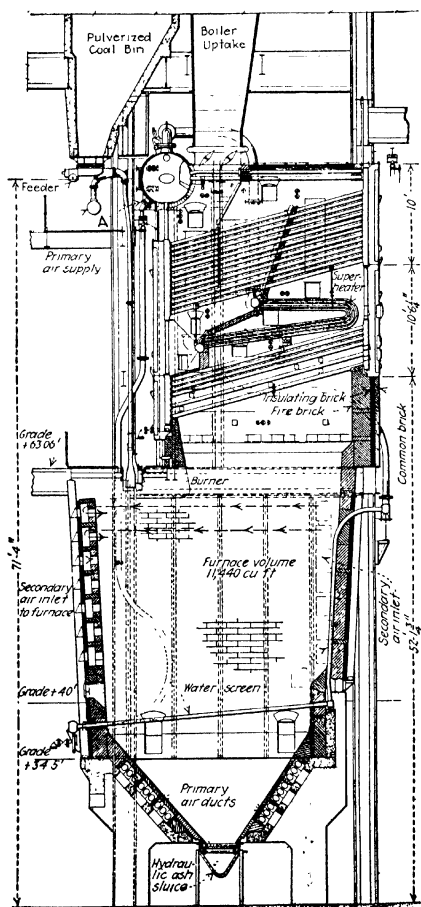
B. CAHOKIA POWDERED-COAL FURNACE—*Power*

the feeders. The total flame length is 55 ft., furnace volume 11,440 cu. ft. per boiler, and the walls and bottom are protected by a water screen of 4-in. tubes on 10½-in. centers connected to the boiler, and by part of the secondary air, which circulates by natural draft through the hollow side walls from the rear to the front, where it enters the furnace with the remainder of the secondary air. The ashes are discharged through hand-operated gates and are washed out through a sluice, from which the finer particles are pumped and the heavy clinker removed by a grab-bucket. It has been found possible to control spontaneous combustion by using gas-tight plates and dampers, and by leaving no warm coal in the driers. The eight boilers are served by ten driers, eight 6-ton pulverizers and one 15-ton pulverizer. No economizers are used, although space is reserved for them should the method of firing be changed later. A 21-hr. test at 214% rating with Illinois coal of 11% ash and 11,713 BTU per lb. as fired, showed 8.18 lb. of 317-lb. steam per lb. of coal, 84.5% efficiency of boiler and superheater, 14.7% CO_2, zero CO, zero combustible in furnace ash, 2.8% combustible in flue dust. The furnace illustrated, on which the tests were made, has water screens on bottom and rear walls, later furnaces have also 23 fin-tubes in each side wall.

CAHOKIA STATION OPERATING RESULTS

1924	BTU per Lb. Coal	Boiler Effy, %	BTU per kw hr Output	Thermal Effy %	River Water Temp., ° F.	Back Pressure in Hg	Avg Sta. Water Rate
Aug.	11,016	79 95	17,951	19 02	79	1 593	12.00
Sept.	10,787	81 38	17,403	19 62	69	1 243	11 88
Oct.	10 783	80 26	17,224	19 99	62	1 148	11.59
Nov.	10 793	80 06	17,290	19 75	49	1 052	11.78
Dec.	10,771	80 22	17,093	19 98	35	0 798	11.63

Power required for·		Kw. Hr. per Ton
Unloading, conveying and crushing		0 40
Drier fans		2 66
Pulverizing mills		16.15
Air compressors (for transporting pulv. coal).		8.52
Total power for coal handling and preparation		27.73

Cost of handling and preparation including maintenance = 36 cents per ton.

L. C. Hobbs and *L. W. Heller* describe tests made on a Stirling boiler at the Brunot Island plant of the Duquesne Light Co, Pittsburgh. The heating surface was 8220 sq. ft., to which 180 sq. ft. water screen was added, making a total of 840 HP, with a B. & W. superheater of 255 sq. ft., later replaced by one of 1031 sq. ft. A 6-ton, 6-roll Raymond mill was used, with no drier, pulverizing to pass 60% through 200-mesh, and the walls were cooled by air which passed to Lopulco screw feeders, secondary air being admitted through the front wall. A 3-pass arrangement, with each pass over one bank of tubes, and a 4-pass, with two rows of tubes placed below the first baffle, to receive radiant heat, were used. Results of tests at various ratings and CO_2 contents are shown in the graphs. The reduced draft with increase in CO_2 shows that increased boiler capacities can be obtained with the same stack and baffle arrangement by simply reducing the excess air (increasing CO_2), which means that the total gas to be handled is greatly reduced, the head lost in friction through the boiler and stack varying approximately as the square of the gas volume. The stack temperature also increases with the amount of excess air, but this would be reversed with very large excess of air.

BRUNOT ISLAND PULVERIZED-COAL FURNACE—*Elec. World*

The *Lykens Plant* of the *Susquehanna Collieries Co.* contains six 5000-sq. ft. boilers with superheaters, operated at 190 lb. pressure, and six 6000-sq. ft. boilers without superheaters, operated at 145 lb., all fired with pulverized anthracite slush fresh from the breaker and washery. The slush, with about three times its weight of water, is pumped 2500 ft. to dewatering tanks, from which it is removed by scrapers and piled in great stacks, at which time it contains 30% moisture, which drops to 10%

PULVERIZED-COAL BURNER AND SPREADER AT LYKENS' PLANT

in 48 hours. The moisture is reduced to 1% in Ruggles-Coles hand-fired double-shell driers, and the coal is then pulverized in *Fuller-Lehigh Screen Mills* so that 82% will go through 200-mesh (the fineness of the slush as received is 70% through $\frac{3}{64}$-in. screen). This fine grinding is necessary to secure proper ignition with coal containing only 8% volatile. Page 428 shows one of the 5000-sq. ft. boilers, in which the ratio of heating surface in sq. ft. to furnace volume in cu. ft. is 3.26 (the ratio is 3.76 in the larger boilers). The combustion chamber is extended in front of the boiler and a 45° slagging shelf leads from the bridge wall to the front ash pit, except in one boiler, in which the construction is as shown by the dot-dash lines. The ash pit slopes to a central trough, from which the ash is sluiced by mine-pump discharge water. The burner discharges downward in a sheet 5 ft. wide by 2½ in. thick into a hollow "spreader,"

RESULTS FROM BRUNOT ISLAND PLANT—*Engrs. Soc. Western Pa.*

which is hinged at the top and can be adjusted to direct the flame according to the load carried. The coal for the 24-hr boiler load is prepared during 16 hr. when the colliery is idle. The cost of handling and preparing is 60 cts. per ton, including operating and maintenance, labor, supplies, power and superintendence, but no investment charges. Pulverizing alone calls for 24 cts., due to the fineness required and the 20% ash, and the pulverized fuel has to be transported 500 ft.

The *Middletown, Pa., Plant* of the *Metropolitan Edison Co.* was designed to use river coal, or if necessary fresh-mined nearby anthracite or bituminous coal. Part of the drier is built like a cooling tower, with coal falling down over two series of louvered passages inside of steel-

LYKENS' PULVERIZED-SLUSH PLANT—*Power.*

LAKE SHORE POWDERED-COAL PLANT—*Elec. World*

plate castings, against a current of part of the flue gases, which are drawn from the drier by a fan which reclaims any fine coal which they may contain. The five *Stirling* boilers in the initial installation each have 14,770 sq. ft. of heating surface, with 7000 sq. ft. of steel-tube economizer surface behind them, and 2150 sq. ft. of superheater surface, and furnish steam at 350 lb. gage and 220° F. superheat. The economizer receives water at 212° F., and beneath it is a "cinder-vane" fan drawing the gases

Furnace volume
above water screen,
11,000 cu ft

Air registers

Furnace width
24 1/4" x 20 deep

El 361.12

El 343.10

EL 334.08

El 312.75   El 312.75

C of boiler house

MIDDLETOWN OR SUSQUEHANNA POWDERED-COAL FURNACE—*Power*

through it and discharging through a steel corrugated flue which serves to preheat the secondary combustion air. At ratings above 350% a portion of the gases is by-passed directly to the fan. For March, 1925, operating 5½ days a week, the coal consumption was 1.233 lb. (16,615 *BTU*) per kw. hr. of net output, using bituminous coal from seven mines and some anthracite from the river bed.

The *Lake Shore Plant* of the *Cleveland Electric Illuminating Co.* has four pulverized-coal units, each consisting of two Stirling boilers with a common combustion space of 29,000 cu. ft. volume, heating surface 30,600 sq. ft. per unit, with twin Foster economizers and B. & W. superheaters, to deliver steam at 250 lb. gage and 250° F. superheat. Undried slack coal of 12,500 *BTU* and 5% moisture is pulverized so that 70% will pass through 200-mesh screen and 90% through 100-mesh, and fed through flat nozzles with openings 14 in. by $\frac{7}{16}$ in., giving the descending stream a larger surface for mixing with additional air and for absorbing radiation from the flame than with a round burner. The air supply to the feeders is preheated to 100° F. by passing through the bottom of the setting, and a water screen of 4 in. pipes spaced 12 in. apart is used. The flame length is 60 ft., and there are 16 burners per unit, eight on each side. Most of the air for combustion is admitted through spring-

balanced dampers at the sides of the settings and passes through hollow walls to the front, where it enters the furnace through numerous 9-in. square openings in the wall under the arch. A test of 19½ hr. at 150% rating showed an efficiency of 83.71% for the boiler and 90.71% for boiler and economizer, with 0 2% combustible in the ash.
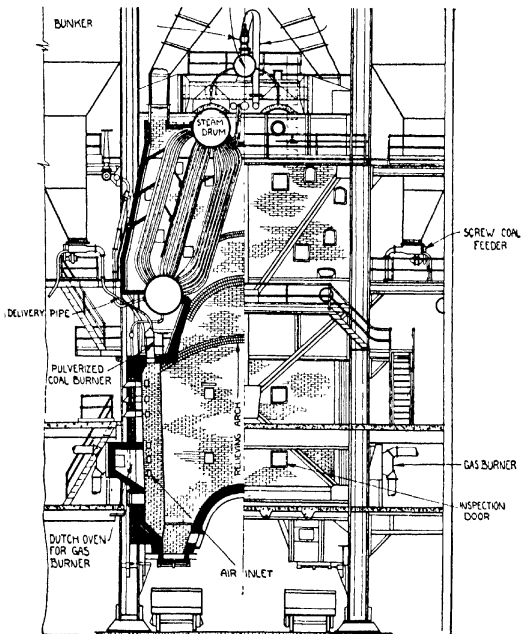
FORD PULVERIZED-FUEL AND GAS FURNACE—*Power Plant Engg.*

The above shows one of the large boilers at the *Ford Plant* at *River Rouge, Michigan.* These are of the 5-drum type, 26,470 sq. ft. each, exclusive of superheater and future economizer. Pulverized fuel is fed from above, through 12 *Lopulco* feeders and 4 triplex burners consisting of three rectangular chambers surrounded on four sides by air ports, the fuel nozzles terminating 9¾ in. from the outlets, giving time for expansion of the mixture containing 10% of the air. Gas is introduced through a dutch-oven setting near the bottom of the combustion space, which is 55 ft. deep and includes 13,200 cu. ft. Various combinations of blast-furnace gas, fuel oil, tar, coal (25% bone coal and 75% Pond Creek), coke, etc., have been burned, and it is now planned to distill high-volatile coal by a low-temperature coking process, recover the by-products and

pulverize the coke for use as fuel. When burning Kentucky coal averaging 13,300 *BTU* per lb., 6 to 10% ash, 97% through 60-mesh, 73% through 200-mesh, the following results were obtained:

Boiler rating, %	150	211	223	260	286
Comb. in furnace refuse.................	0	0	0	0	0
Comb. in flue dust, %....	...	4.0	12.0	12.0	34.8
Lb. water per lb. coal....................	8.22	8.38	8.57	8.42	8.74
CO_2 in uptake, %.....................	11.6	12.9	13.5	15.3	14.6
Heat absorbed by boiler and superheater, %	77.8	79.6	82.0	80.9	82.2
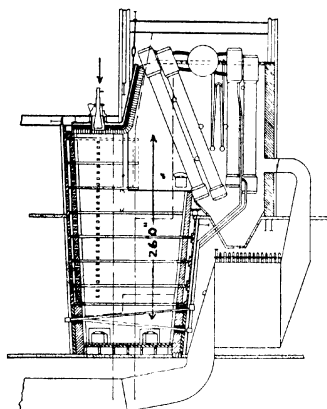
ROCHESTER GAS & ELEC. CO. FURNACE.—*A.S.M.E*
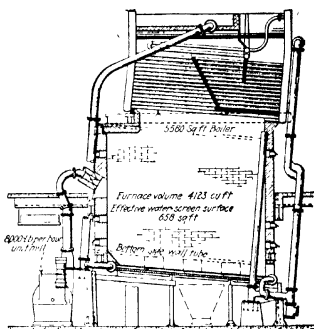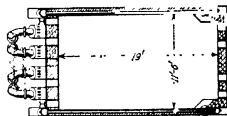
ASHLEY STREET PULVERIZED-COAL FURNACE—*Power*

The *Rochester Gas & Electric Co.* plant contains an 8750-sq. ft. Bigelow-Hornsby boiler, with Foster superheater of 1055 sq. ft. and Sturtevant cast-iron tube economizer 2390 sq. ft. Furnace is of hollow-wall construction with steel casing, 4200 cu ft. volume above 157-sq ft. water screen, and 655 cu. ft. below. Four fantail burners are used. Using Pennsylvania Lucerne Mine coal of 13,200 *BTU* per lb., 95% through 60-mesh, 60% through 200-mesh, the following results were secured:

Boiler Rating, %	157	177	199
Water evap. per lb. of coal	9.44	9.50	9.10
CO_2 in gas from boiler, %	14.3	14.1	15.6
CO_2 in gas from economizer, %	13.0	13.0	13.8
Heat absorbed by boiler and super- heater, %	80.6	82.4	78.9
Heat absorbed by boiler, superheater and economizer, %	84.8	86.1	82.5

A similar furnace under a 12,660-sq. ft. boiler was fired with mixtures including 50 to 65% of Rhode Island graphitic coal, containing 9770 BTU per lb. as received. Its volatile was so low (2.60%) that it was practically impossible to start fires with it alone, but satisfactory economic results were obtained when it was mixed with New River coal.

E. H. Tenney describes a 5580-sq. ft. water-tube boiler in the Ashley Street Station, St. Louis, equipped with convection superheater and 6854-sq. ft. economizer serving two boilers, special furnace walls being supplied to permit operation with pulverized coal the ash of which melted at 2000° F. and contained 24% iron oxide The Bailey furnace lining used consists essentially of cast-iron "brick" bolted to water-screen tubes spaced 6 in. centers, intimate contact between the lining and screen being provided by a special paste filler of high heat conductivity. The side-wall lining has a refractory facing integral with the castings and composed of a large percentage of carborundum, while the bottom lining is bare cast iron. The furnace volume is 4123 cu. ft. and total effective water-screen surface (half the external tube area) 658 sq. ft. A simple unit pulverizer of 8000 lb. capacity supplies undried coal to four burners, the fineness being 55.2% through 200-mesh, 68.2% through 150-mesh, 78.5% through 100-mesh, 86% through 60-mesh. Turbulence of air and coal is secured by a deflecting cone in the coal nozzles and a deflecting ring with spiral vanes in the air chamber around the burner. The following tests are reported:

	No 1	No. 2
Output of boiler, % of rating	330	225
Efficiency of boiler and economizer, %	82 9	85.4
CO_2 at uptake, %	14.5	13.7
Moisture in coal, %	11.7	11.3
BTU per lb. coal as received	10,770	10,820
Lb. of coal per cu. ft. per hr	1.8	1.2
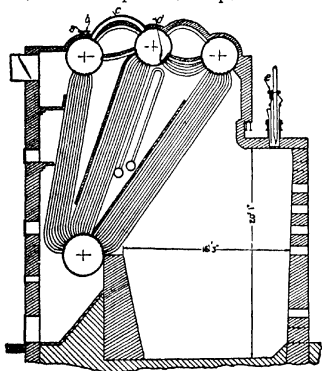
PULVERIZED-COAL FURNACE AT RIVERMINES

VARIATION OF FLUE-GAS TEMPERATURE WITH RATING

a, Feed water; *b*, steam; *c*, auxiliary steam tubes; *d*, Weaton continuous blowdown; *e*, Lopulco duplex burners.

The *Bureau of Mines* reports tests on two *Stirling* boilers, each of 7688 sq. ft. heating surface and 878 sq. ft. superheater surface, at *Rivermines, Missouri.* The boilers were set singly and connected by steel breeching to a brick stack 200 ft. high, and each was equipped with two 3½-in. diameter *Lopulco* duplex, round-nozzle burners cut at a 45° angle, with the long lip next to the front wall and slightly curved away from it. There were 27 air inlets through the front wall, with slanting cast-iron doors hinged at the top, and four cleaning-out doors at the floor level. The coal was Southern Illinois screenings, and was pulverized so that 95% passed through 100-mesh and 75% through 200-mesh screen. The general results are shown in the following table, and the flue-gas temperatures on one test in the chart. In test No. 1, at average rating of 202%, the flames reached to within 3 ft. of the bottom of the surface, and generally extended through the first pass and entered the second bank of tubes. In No 2 they extended through the first pass only when the rating was close to 200% or when the excess air was low.

SUMMARY OF RESULTS OF BOILER TESTS

No of boilers.....	1	1	1
Test number	1	2a	2b
Duration, hours	48	119.22	93.28
Condition of coal when burned	Dried	Dried	Undried
Rating, %	202	155	155
CO_2, %	12 9	13 7	13.6
Temperature of flue gas, ° F.	666	561	567
Temperature of superheated steam ° F	546	525	534
Overall thermal efficiency, in % of heat in coal supplied to preparation plant	72 6	77.3	78.2
Thermal efficiency of boiler only in % of heat in coal supplied to boilers	74 4	78.8	78.4
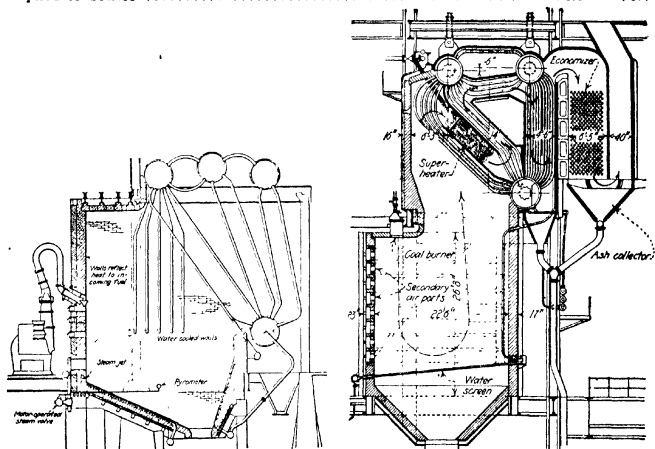
CONSTANT-TEMPERATURE PULVER- 1. PULVERIZED-COAL FURNACE AT
    IZED-COAL FURNACE—*Power*   VITRY—*Power*

Neither efficiency includes the power used in preparing and conveying the coal.

The constant-temperature furnace of the *Furnace Engineering Co.*, for use with the unit system of pulverized fuel, is designed to maintain at the boiler tubes a gas temperature below the fusion point of the ash and the softening temperature of the brick work, preventing the accumulation of hard ash in the boiler tubes and the erosion of the furnace walls. Sloping boiler-tube surface is placed in the floor of the furnace, covered with cast-iron blocks which transmit the heat to the circumference of the tubes, while tubes on the walls tend to reduce the brickwork temperature. Ash is allowed to accumulate and cover the floor during light loads, but is removed by intermittent shots of steam from nozzles during heavy loads, thus exposing additional direct heating surface. A pyrometer placed in the furnace walls controls a motor-operated steam valve and the air supply, permitting the maintenance of constant gas temperature to conform with the maximum burning efficiency of the fuel.

Fig. 1 shows a pulverized-coal installation at *Vitry, France,* under a Ladd-Belleville Boiler of 19,270 sq. ft. heating surface, 5160 sq. ft. superheating surface, and 14,000 sq. ft. steel-tube economizer surface. "Lopulco" burners are used.

H. W. Brooks describes the "well-type" burner for pulverized coal, in which four tangential jets discharge the fuel into a water-cooled well below the furnace, in such a manner as to impart a whirling or tornado effect to the flame. Above the well is a dispersion chamber in which the hot gases are allowed to expand and be reduced to a velocity which will not erode the boiler tubes but sufficient to scour off the insulating gas film and keep the tubes clear of deposited ash. It is stated that the combined volume of well and dispersion chamber can be made substantially less than the combustion space provided for stokers and furnace in the ordinary boiler setting, while commercial-scale tests on a furnace similar to the one illustrated showed efficiencies 3 to 5% higher than with the other methods of firing, with flatter curves of efficiencies at various ratings. Combustion rates of over half a million *BTU* per cu. ft. per hr. have been attained.
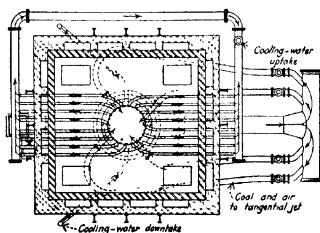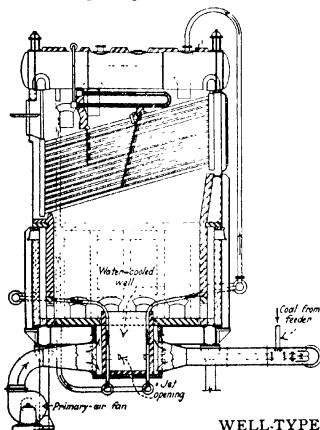
WELL-TYPE FURNACE—*Power*

Pulverized fuel has been used with the *Bettington* vertical-tube boiler, n which the particles of burning fuel have a free upward and downward)ath, and the combustion chamber is enclosed by vertical water tubes connecting the upper and lower drums, with the inner tubes encased in ire brick except at the very bottom. London *Engineer* states that efficiencies from 74.9 to 82 6% have been obtained, the latter with a Wetbank slack containing 2.2% moisture.
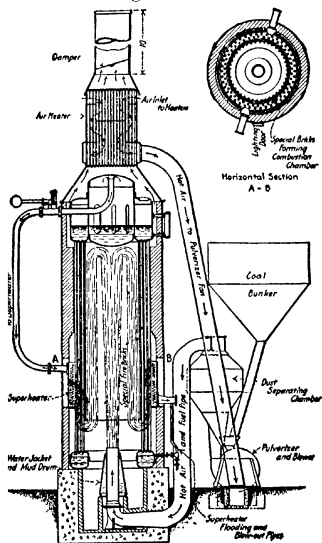
BETTINGTON BOILER FIRED WITH
PULVERIZED FUEL—*Power*
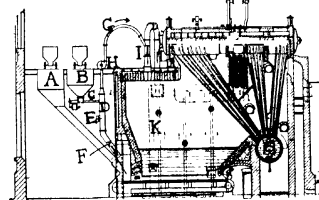
COMBINATION CHAIN GRATE AND
PULVERIZED-COAL FURNACE
—*Z. d. V. deut. Ingr.*
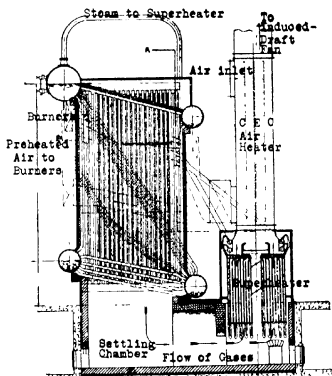
A COMBUSTION STEAM GENERATOR

The "*Combustion*" *Steam Generator* employs radiant-heat elements (with welded fins) in the four walls of the combustion chamber, with nearly-horizontal convection elements forming the bottom. The installation shown in Fig. A, containing 2000 sq. ft. heating surface, produced over 70,000 lb. steam per hr, at 88% efficiency. This represents 1150% of nominal rating for the heating surface used.

The *Schuckert-Petri* combination furnace makes possible the use of coarsely-ground undried coal, with reduced investment and less danger of explosion.

A, Bunker for grate coal   *B*, Bunker for ground coal   *C*, Feedworm.   *D*, Air separation chamber   *E*, Air supply.   *F*, Coarse particles   *G*, Fine particles.   *H*, Fan.   *I*, Preheated air to burner.   *K*, Cooling passages in wall.

Powdered coal is distributed by trucks to small consumers in Seattle. Sub-bituminous coal, sometimes running as high as 25% moisture, is pulverized in a plant 15 miles from the city and is brought in by sealed railroad cars, made of wood with asbestos board lining, and sheet iron lining to the hopper bottom. *B. J. Cross* describes the trucks used in distributing the coal from the storage station in the city. When discharging, they are tilted at a 45° angle, and a canvas sheath is fitted between the spout and the consumer's bin, and an air pipe connects the top of the bin with the top of truck tank. It is filled in the same position, and the intake and discharge openings are closed by tight-fitting ratchet gates. The storage bins are so far as possible made air-tight to prevent absorption of moisture from the atmosphere, and circulation or renewal of the enclosed air. Serious heating has been observed only when the coal has been accidentally wetted, which accords with the general belief in regard to the storage of lump coal. A similar system is in use in Minneapolis. Special railroad tank cars are used in Germany.

Operation.—The *Bureau of Mines* states that fires are started with powdered coal very much the same as with oil. One or two burners are lighted at a time. When there are more than two burners the center burners are lighted first. The feeders are started at their lowest speed, about 25 to 30 rpm., and supply about 500 lb. of coal per feeder per hr. The air pressure on the feeder should be low—5 or 6 in. of water. Then the stream of coal and air is lighted with burning oil waste attached to a steel rod about 6 ft. long and inserted into the furnace either through the burners or through the top row of the air inlets in the front wall. If the air pressure on the feeder is not too high, the coal will light readily and stay lighted. If too high the flame may be blown out. It is therefore better to light the coal with very low air pressure and, after the coal starts to burn, to increase it. It is also better to put the lighted oily waste into the furnace first before the coal is turned on to avoid the possibility of filling the furnace with powdered coal before lighting it, causing an unpleasant puff of smoke through the burners. After the two central burners are well lighted the burners on each side can be slowly turned on and will ignite from the central burners. When all have been lighted, the feeders can be gradually speeded up and the air pressure increased. When a furnace is started cold there may be some smoke, but not as bad as with oil. With practice a furnace operator may be able to put a cold boiler on a line within one-half hour. The most important requirement for obtaining the best results is to keep the flames from striking the boiler tubes. For observation each furnace of the Lakeside plant was provided with two large observation doors, one on each side of the furnace, about 3 ft. below the boiler tubes. There were also two small observation doors on each side of the furnace, about 1 ft. below the boiler tubes.

When the flames strike the tubes it shows that a large amount of solid particles of unburned coal is passing out of the furnace with the gases. The amount of slag deposited is greatly increased; and by clogging the gas passage it may necessitate a shutdown. Losses from incomplete combustion and from slag deposits on the tubes are particularly bad if the flames are smoky brown. The best furnace conditions are obtained when only the tips of the flames touch the tubes and the flames are clear and almost transparent. Improper adjustment of the air supply may cause a general deficiency of the air supply in the furnace, so that coal can not burn completely, indicated by the flames striking the tubes over the entire

width of the furnace. The furnace temperature is usually high and molten ash may be seen trickling down the side walls and back wall. Accumulations of ash on the walls will soften and slide down to the bottom of the furnace and there will be dark gray smoke at the top of the chimney. The remedy is to increase the draft in the furnace so that more air will flow into the furnace through the hollow walls or the front openings. If the draft can not be increased, the rate of feeding coal must be reduced until the furnace has cleared up.

Local deficiency in the air supply may bring about somewhat similar conditions. If the feeders on one side of the furnace are running faster than those on the other side, the flames may be seen to strike the tubes on the fast side, although they may be clear and not nearly touch the tubes on the other side. The obvious remedy is to slow down the feeders on one side and speed up on the other, if the rate of steaming must be maintained.

When the rate of steaming must be increased, the speed of all the feeders should be increased in the same proportion, in order that all parts of the furnace may be made to burn equal amounts of coal. The draft must always be increased in greater proportion than the rate of feeding coal, because the rate of flow of air into the furnace varies as the square root of the draft. Therefore, if the rate of steaming must be doubled, the draft in the furnace must be quadrupled, in order that the coal and air supply will be maintained in the proper ratio. If steaming rate is to be increased by 50%, the draft must be increased by 125%. Flame may strike the tubes because the flames turn up before descending low enough into the furnace. The path of the coal is greatly shortened and the coal leaves the furnace before it is burned. This is usually caused by too low an air pressure on the feeder or possibly by too high a draft, so that the air pressure on the feeders can not force the coal down into the furnace against the air rising through the furnace. Under these conditions incomplete combustion and the slagging of tubes may be accompanied by high excess of air. This smoky condition can be remedied by reducing the draft and increasing the air pressure on the feeders, forcing the flame down into the furnace, making its path much longer, so that combustion is nearly completed before the flame reaches the tubes. If flame strikes the tubes because the rate of combustion is too high, adjusting the drafts and air supply will not help; usually it can only be prevented by reducing the rate of feeding the coal. If the burners are equipped with steam jets, turning them on will reduce the smoke appreciably, and also reduce the striking of the flames against the tubes, but the flames may be driven against the bottom of the furnace and melt the ash, making its removal difficult.

Safety.—The regulations for the installation of pulverized fuel systems adopted May, 1924, by the *National Fire Protection Association,* include the following: Class A Systems are indirect, or those in which the fuel is intimately mixed with air at the point or points where used and involving storage bins at points of consumption. Class B systems are direct, or those in which the pulverized fuel is fed to a fan by which it is blown as a combustible mixture through large pipes to furnaces or other points of combustion. In the case of circulating systems of this class, the unused fuel is returned to the initial point to again be blown through the line. Unit systems are those in which the fuel is pulverized at or near the point or points of use and delivered directly from the

pulverizer into the furnace by means of fan or blower, which may be an integral part of the apparatus, the air being admitted in the apparatus or in conjunction with the fuel, and no bins being employed.

General Regulations for Classes A and B: Pulverizing should be done in a separate detached building, or in a special room or floor cut off by masonry walls and floors, and with communication only by fire-resistive stairs or vestibules with two fire-doors. Structural members should have little surface for accumulation of dust and be accessible for cleaning. 10% of the wall area should be of thin glass, nowhere further from any part of the room than the least horizontal dimension. Wired glass should only be used where necessary for protection from outside fire, and hung so that it will swing out in case of explosion. Compressed air should not be used for general cleaning, except in connection with water spray, but may be used for cleaning motors. Dust should be removed by non-portable vacuum systems, properly grounded, with non-ferrous nozzles, and with the dust separating before it reaches the exhauster, with no perceptible discharge of dust into the room. Portable compressed-air tanks may be used, with no electrical equipment in the room. A magnetic separator should be installed ahead of the pulverizer for removing tramp iron. It should be possible to cut off power from outside the building. Cloth-type dust collectors should be provided with tight metal enclosures, with the fabric electrically grounded; other collectors should be non-combustible. Safety relief vents (see figure) should be provided on the mill discharge and at elevator heads, storage bins and dust collectors. Blowers should be used only for blowing fuel or secondary air, should

RELIEF VENT
FOR PULVERIZED COAL
—Natl. Fire Prot. Assn.

a - Weather Hood.
b - Cover Plate.
c - ¾" Felt Gasket.
d - Non-Corrosive Hinge.
e - Counter-weight.
f - Angle Iron Rim.
g - Vent
h - From Apparatus.
i - Discharge.
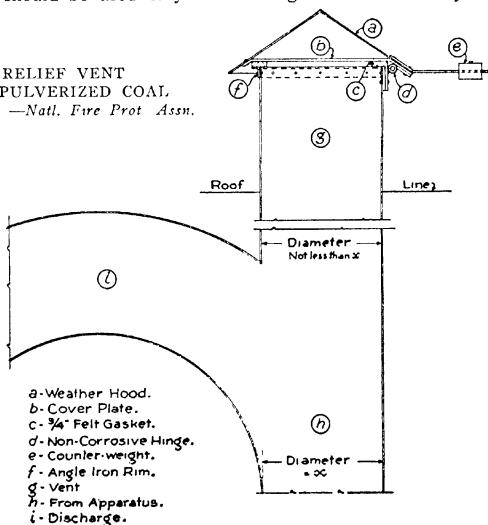
not have internal bearings, and connections should be such as to prevent leakage of fine dust. Drying department should be separated from pulverizing by walls having fire resistance of at least one hour. Coal to be dried should not come in contact with products of combustion except at distance of one-half the drier length and not less than 12 ft. Dried unground coal should not be stored for more than four hours. Ground coal may be stored as follows:

Temperatures of Coal Entering Mills	Maximum Quantity of Pulverized Coal (Other Than Anthracite and Coke) Which May be Stored	
250° F.	4 hours' supply	
225° F.	8 "	"
200° F.	12 "	"
175° F.	16 "	"
150° F.	18 "	"

Pipe lines should be of lap-welded steel pipe, seamless steel tubing or butt-welded sheet steel No. 10 gage or thicker, fittings of cast iron (125-lb. American Standard flanges) or butt-welded sheet steel not less than No. 10 gage, provided with removable wearing plates at all points subject to abrasion, with the size increased to give proper effective diameter; joints to be made by standard pipe fittings or 125-lb. American Standard flanges not less than ¼ in. thick welded to pipes. Hand extinguishers and sprinklers should be placed where introduction of combustible material into pulverizing room makes it necessary.

Special Regulations for Class A Systems: Pipe lines between mill bins and points of consumption or storage should be of standard full weight steel pipe, fittings equal to 125-lb. American Standard, with dusttight joints and away from open flames or lights and sources of radiated heat. Storage and furnace bins should have smooth interiors with no pockets for accumulation of fuel, should be dust-tight, whether built of steel or concrete, and be so set that radiation will not materially raise the temperature. They should be normally tightly closed, except for vent openings, and if filled by air current, the arrangement should be such as to insure a minimum dust cloud within the bin. There should be an overflow warning, and no pressure within the bin. Screw conveyors should be driven from the exit end, and if in series should be interlocked so that the stopping of the last stops the others, or the junction points should be outside the building, with a normally-closed spillway or relief valve. No wires, except in conduits, should be hung from apparatus.

Regulations for Class B Systems: Piping and fittings should be designed to withstand the maximum working pressure that may be exerted, with a positive check in each switch or branch line to burner. All joints and valves shall be dust-tight, and the lines shall be away from open flames or lights, and at safe distances from furnaces, etc. The primary blower shall afford a higher pressure than the secondary or booster, and both motors shall be connected to the same circuit breaker. Bins as under Class A. Cyclone separators should not be placed directly over storage bins.

Regulations for Unit Systems: The pulverizer shall be controlled remotely at a readily accessible location and at the mill, and if heated air is used, it must be heated by an indirect method. The magnetic separator should be between crusher and pulverizer, if the former is used. No single apparatus should supply more than two furnaces, and the volu-

metric capacity of the system, including the housing of mill, mixing chamber (if any), fan and all of the piping, shall not exceed 100 cu. ft. unless vented as under Class A. Each discharge pipe should be provided with positive shut-off gate or control. When two discharge pipes from separate pulverizers deliver to the same furnace through the same nozzle, a valve should be provided at the junction of the discharge pipes which will automatically shut off the discharge pipe when not in use. Every vertical or nearly vertical pipe and every angle greater than 45° should be vented as under Class A. Pipe lines, crushers, driers and other equipment if used, to be as under Classes A and B.

Instruction Cards.—An instruction card, including the following precautions relating to safe operation, to be conspicuously posted in the pulverizing plant, boiler plant and in buildings where pulverized fuel is used:

(*a*) The crushing, drying and pulverizing plant should be under the supervision of a thoroughly competent and reliable foreman, and only competent and reliable workmen should be employed in connection with those operations.

(*b*) The use of shavings or other similar light combustible materials for starting fire in drier furnace is prohibited.

(*c*) The rotation of the drier shall not be stopped while it contains a charge of fuel.

(*d*) Whenever a plant has been idle for a period of two days or more, all storage bins shall be thoroughly inspected before resuming operation.

(*e*) Manhole or inspection openings of furnace bins shall not be open while fuel is being discharged into the bins.

(*f*) Operators are cautioned against causing leaks in pipe lines or bins by hammering.

(*g*) Damper in drier chimney uptake shall be wide open when fire is started.

(*h*) In Class B Systems, if fuel supply line becomes clogged, the furnace shall be immediately cut off and the secondary air stopped. When obstruction has been cleared and before starting fan, a thorough examination shall be made to ensure the removal of smoldering particles of fuel.

(*i*) All fuel supply lines (of Class B and Unit System types) shall be blown clear of fuel when shutting down at close of day.

(*j*) All conveyors and elevators shall be tightly and securely enclosed and never opened while running. Previous to opening, machinery shall be stopped and dust allowed to settle for a period of 20 minutes.

(*k*) All stationary lights shall be protected with dust-proof globes and wire guards. Only daylight or hand flashlights shall be used when inspecting the interior of coal storage bins and pulverizing and coal conveying apparatus when in operation. When apparatus is not in operation guarded drop lights with dust-proof globes utilizing super-service portable cord may be used. Special dust-proof outlets and an adequate number of such cords shall be provided in every pulverizing plant. All conveying and distributing piping shall be inspected daily and any leaks promptly repaired.

(*l*) Smoking and the use of open lights or torches shall be prohibited in the crushing, drying and pulverizing plant.
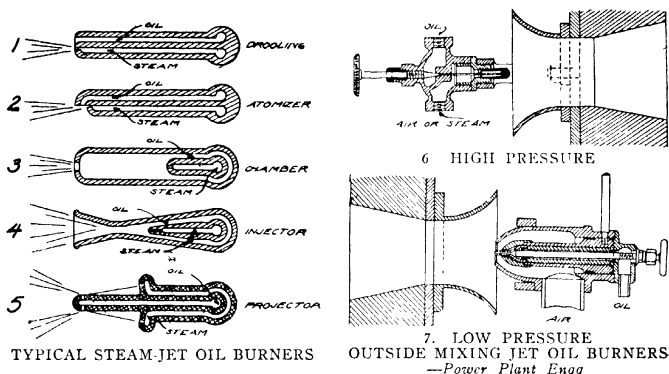
TYPICAL STEAM-JET OIL BURNERS

6   HIGH PRESSURE

7.   LOW PRESSURE
OUTSIDE MIXING JET OIL BURNERS
—*Power Plant Engg*

BURNING OIL FUEL

For efficient combustion, an oil fuel must be introduced into the furnace in a thoroughly atomized state, it must come into contact with the proper amount of air, and there must be sufficient space for combustion to be completed before the gases strike the boiler heating surfaces.

Burners.—The "burners," which are really feeders, are of the steam- or air-jet atomizing type or the mechanical atomizing type, the latter receiving oil under pressure. Among steam-jet burners, sketch No. 1 shows the drooling type, in which oil oozes onto the outcoming steam spray, No. 2 the atomizer burner, in which the orifice is turned down so that the steam spray sweeps off the oil, No. 3 the chamber burner, in which the oil and steam are mixed and a mist formed in the inner or expansion chamber, No. 4 the injection burner, in which the oil is sucked in by the steam jet and expanded in the flared nozzle and No. 5 the projector type, in which the steam jets are set back, giving the steam opportunity to expand before picking up the oil. Figs. 6 and 7 show outside mixing burners, the jets for the oil and impelling fluid being located outside the furnace and throwing a cone-shaped spray which enters the furnace through a Venturi orifice, sucking in air for combustion. In mechanical burners high-pressure oil is brought to the nozzle by helical passages or guide vanes giving the fluid a swirling motion, or is fed through a hollow shaft to the surface of a rapidly-rotating disk.

In the *W. N. Best Calorex Burner* the oil and the pressure fluid (steam or oil) are mixed externally, at right angles, giving either a narrow or fan-shaped flame. The by-pass is used for cleaning. The *Rogers-Higgins Burner* is used with steam or air, mixed internally or semi-externally, the flow being regulated at the exit. The *Koerting Cyclone Oil Burner* is intended for use where forced draft must be employed, or in order to utilize a low pressure pump. Compressed air issues around the atomizing nozzle with a gyratory motion. Straight air atomizers are also
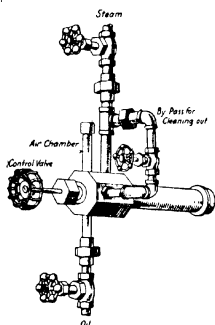
ROGERS-HIGGINS OIL BURNER
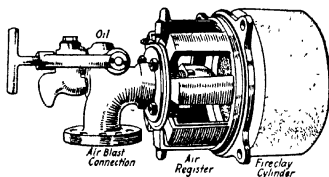
KOERTING CYCLONE OIL BURNER
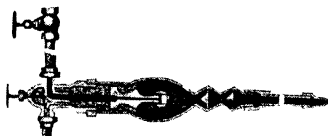
QUINN OIL BURNER
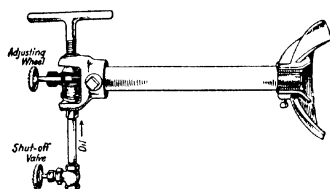
COEN OIL BURNER
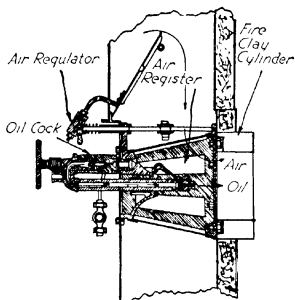
KOERTING MECHANICAL BURNER
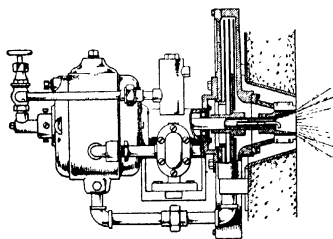
RAY ROTARY OIL BURNER
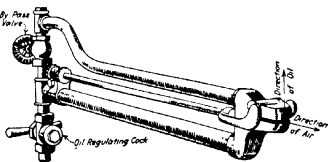
BEST OIL BURNER

built, and even gravity burners. In the *Hammel Burner* steam and oil are mixed in the chamber *C*, which has renewable plates, entrained moisture escaping under the lip. In the *Staples and Pfeifer Burner*, the steam or air flows through the outer passage, while the oil issues at the point *P*,
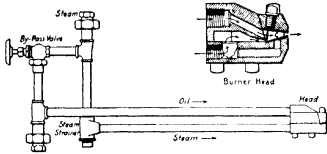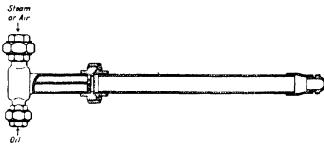
HAMMEL OIL BURNER

S & P OIL BURNER
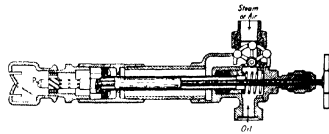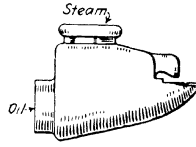
OWENS OIL BURNER

Fantail Burner

FOERST OIL BURNER

under regulation by the rod. In the *Owens Burner* the atomizer and fuel are mixed in a long passage, while in the *Foerst*, the pipes lead to a small burner placed directly inside the boiler front.

The burner of the *Coen Mechanical System* receives oil under pressure and gives it a whirling motion. The adjusting wheel operates the small ball at the exit, by which the flow is regulated, or reduced to the minimum without shutting off In the *Koerting Mechanical System*, the heated oil is pumped to centrifugal spray nozzles, surrounded by a register for admitting air. In the *Ray Burner* the oil is atomized in a revolving open cup, and directed into the furnace by a low-pressure air current. Motor, atomizer and blower are mounted on a swinging stand. In the *B. & W. Burner*, the oil, under pressure, passes through tangential grooves to a circular exit orifice, the whole being surrounded by an air register.

In the *Quinn Oil Burner*, oil from the upper pipe flows under pressure through the central tube, then through a restricted tube and against an abutment which breaks it into spray and reflects it back to an annular outlet, where it is brought in contact with a small amount of steam and is forced out through the tip of the burner as a mist or gas.

Mechanical burners have been widely used in marine work, due to the necessity of minimizing make-up water consumption. *Hugh E. Weightman* states that they show increased thermal efficiency in any plant which can be operated at a reasonably continuous rating, although this may be offset in a small plant owing to the higher investment and maintenance charge. They are not so satisfactory as steam-jet burners when operated at less than full capacity, and often there is not room at the furnace front to install enough burners of the mechanical type to be cut in and out to take care of extreme variable ratings. However, it is customary to use in each furnace a number of relatively small burners, and control is had by regulating the stack damper, by cutting individual burners in and out, and by changing the oil pressure (ranging from 125 to 250 lb.) in all burners simultaneously. The flame from mechanical burners is well distributed,

is practically noiseless and comparatively soft, without jet or blowpipe action. *S. E. Derby* states that 83% overall boiler-furnace efficiency is obtainable with 5000-sq. ft. boilers under test conditions with mechanical atomizers, and 73 to 78% in ordinary operation. The power consumption of the mechanical atomizing system of one of the largest oil-burning plants in New England was for six months less than ⅔ of 1% of the total steam generated, but this does not take into consideration the heat returned to the oil during preheating or the heat of the exhaust steam from the oil pump returned to the feed-water heater by means of a small surface condenser used as a preheater on the make-up line.

Nathan E. Lewis states that mechanical atomizing oil burners are gradually displacing steam atomizing burners in central plant service. Steam burners are simple in construction, cost little for maintenance, require less draft and are efficient for use in industrial plants with fairly steady loads at not over 200% of boiler rating. Mechanical burners depend solely on pressure to break the oil up into a fine mist while passing through a small orifice in the burner tip, the mist leaving the burner becoming mixed with the proper quantity of air and giving quick combustion with a short conical flame instead of a long flat one. The furnace design is complicated by temperatures as high, or higher, than those produced with stokers or pulverized coal. The maximum amount of oil fed by a steam burner is 1200 to 1300 lb. per hr., while mechanical burners in stationary practice handle not over 1600 lb. oil per hr., the limit being fixed by the draft and forced-air conditions. Steam burners are installed in a single row, on account of the manner of air admission and the character of the flame, while mechanical burners can be installed in two rows, the combustion air being admitted through the register of the burner.

If the oil fed to a boiler furnace is not heated sufficiently, it cannot be atomized properly and the burner will smoke heavily, no matter how much excess air is admitted, while if the oil is too hot, steam is wasted in heating it, pulsations are liable to occur in the combustion, and burner capacity is decreased. With steam atomizing burners the oil temperature at burner should be 130° to 190° F., and oil pressure at burner 40 to 60 lb, the oil heater being built for 150 lb. on the oil side and 60 lb steam pressure on the shell. Mechanical burners should receive oil at 200° to 280° F. and 100 to 250 lb. pressure, the heater requiring live steam and being built for steam and oil pressure of 250 lb. and upward. All pipe lines should be large, and elbows and sharp bends should be avoided, to take care of variations in viscosity, while joints must be very tight to prevent fire hazard. The present practice as to furnace volume ranges from 0.15 cu. ft. per sq. ft. heating surface (0.35 cu. ft. per lb. of oil per hr.), for industrial boilers with steam burners, to 0.5 cu. ft. per sq. ft. of heating surface (0.5 cu. ft. per lb. oil per hr.) with mechanical burners in central stations. These large volumes permit economical operation at high rating, without tube trouble from localized flame on the boiler heating surface. The small volumes used in marine practice are made possible by the use of better fuel and by special precautions to protect the tubes. With steam burners, air is admitted to stationary furnaces through the openings in a false checkerwork floor above the furnace floor, and small changes in the checkerwork pattern or in the position of the impeller plate with a mechanical burner will often prevent the laning of excess air and afford improved efficiency. Oil-fired boilers are now often required to evaporate

8 to 10 lb. water per hr. per sq. ft. heating surface, and with large furnaces 60 lb. per hr. can be evaporated per cu. ft. of furnace volume, or 150 to 180 lb. per cu. ft. in marine work, with best feed water and best attendance. With steam burners, allowance must be made for the long travel of the flame, which would erode brickwork faster than would the conical flame from a mechanical burner

Furnace brickwork is often protected from the high temperatures produced by mechanical burners by the use of air-ducts. The unit illustrated, Fig. A, has 19,884 sq. ft. boiler heating surface, 11,660 sq. ft. air heater surface, and a maximum rated capacity of 150,000 lb. steam per hr., equivalent to an evaporation of a little over 7½ lb. per hr. per sq. ft. boiler heating surface. Air is taken at point P about 17 ft. above boiler-room floor, passes downward through ducts back of the rear wall of the furnace, then under the floor to ducts in the side walls, through which it rises to a breeching B leading to the air heater A, through which it is drawn by fan F and delivered to the mechanical oil burners. A solution of the refractory problem will be had when brick can be made in needed quantity and at a permissible price, which will have less plastic deformation and activity or spalling, a higher fusing point, and less tendency to slag than the present commercial firebrick exhibit   Expansion and contraction leave a brick geometrically similar to its original shape. Plastic deformation changes the shape of a brick and appears in the best grades of fireclay brick under a load of 25 lb, when the brick is exposed to temperatures of 2200° to 2400° F, and under a 10-lb. load at temperatures about 200° higher. As furnace brickwork sometimes carries a load of 15 lb. per sq. in. and furnace temperatures may run as high as 2400° with hand-fired coal, 2700° with stoker-fired coal, and 3000° with oil fired by mechanical burners, plastic deformation is ranked as one of the most serious causes of high maintenance expense of furnaces. The activity of a firebrick is the rate of its expansion or shrinkage with temperature changes   When the volumetric change is small under a considerable range of temperatures, any resulting injury to the masonry is likely to take the form of bulging or cracking walls. If the expansion or shrinkage is large under a narrow range of temperature, the injury is likely to be spalling. The side of a brick exposed in the furnace will have a temperature nearly equal to the flame temperature. The fusing point of such a brick must therefore be at least 100°—preferably 200°—above the flame temperature. As the fusing point of first-class fireclay brick exceeds 3100° F., fusion causes relatively little trouble in well-designed furnaces.

Steam-jet burners giving a flat flame can only be applied single-deck, as an upper tier would not receive sufficient air for proper combustion, but *Kingsley L. Martin* calls attention to the conical-spray type of steam jets with individual air registers, which are installed in the same manner as mechanical burners. They utilize say 20 lb. oil pressure instead of 150 to 200, they do not require a dangerous degree of preheat in the oil, have oil passages not under ⅛ in. in diameter and do not require discharge strainers, and the heater can even be by-passed and oil used as it comes from the tanks. By varying the oil and the steam from master valves for either a single furnace or a battery, the burner capacity can be varied from that of a pilot light up to 250 or 300% of rating without change in the flame angle, which is fixed by the shape of the orifice, or in the position of the atomizer or register adjustment. For the ordinary working range of the boiler, the steam is unchanged and oil alone regulated. Two 600-
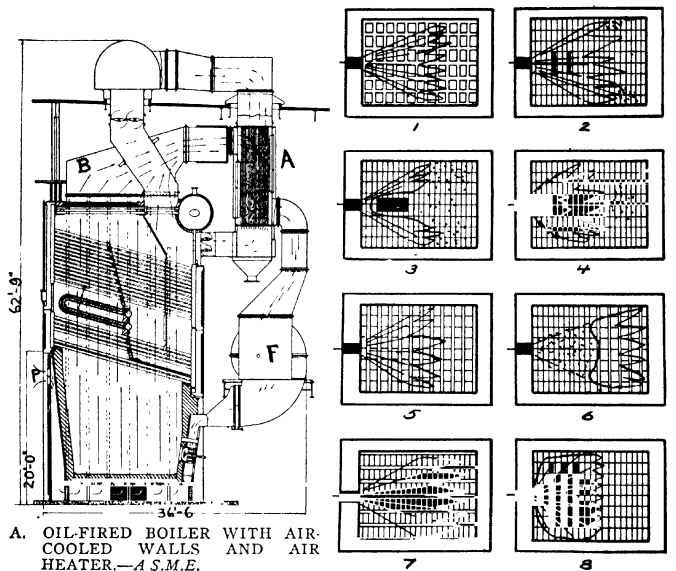
A. OIL-FIRED BOILER WITH AIR-
COOLED WALLS AND AIR
HEATER.—*A S.M.E.*

B. FURNACE FLOORS—*Power Plant Engg.*

HP. boilers requiring 1.50 in. of air pressure to develop 250% rating on mechanical atomizing were operated on 0.20 in. natural draft with steam atomizing equipment, using four registers and burners in each case. A 600-HP. B. & W. boiler using water-gas tar developed an average of 230% rating for 24 hr. with only 9 lb. (gravity) tar pressure, 0.15 in. draft (natural) in furnace, 14% CO_2 and no smoke; maximum rating 270% at 0.25 in., change from 75 to 230% effected in a few minutes by operating the boiler tar-supply valve only. A 625-HP. B. & W. boiler with only 955 cu. ft. furnace volume developed approximately 250% rating using four steam-atomizer registers on forced draft, with oil pressure 78 lb., air pressure at register 0.98 in., and negative draft in the furnace of 0.05 in.

Weightman calls attention to the tendency of small orifices in any type of burner to clog, and to the desirability of means for blowing all the oil out of the burner when cutting out, to prevent carbon deposits due to furnace heat. He also recommends a valve with a wide, short slot, in place of a needle regulating valve with its narrow circumferential passage.

Furnaces.—Oil-fired furnaces should be long enough and high enough to give long flame travel without direct impingement either on brickwork or on boiler tubes. *Parker* and *Derby* recommend 2 cu. ft. furnace volume per 10 sq. ft. boiler heating surface, which permits of operation at 300% of boiler rating with mechanical burners and at 200% with steam oil-

burners. If 4 to 6 cu. ft. are used, the added advantage may be offset by radiation from the furnace walls and floor.

Although coal settings can sometimes be used by building a brick checkerwork with ⅜ in. air spaces on the grates, the "low setting" is preferred, in which the brick are laid on the floor. For a boiler with a long unobstructed furnace, such as a horizontal return tubular, a Heine or an Erie City, *Nelson* suggests placing the burner in the firing door. For short-furnace boilers, the best arrangement is to put the burner at the back, shooting forward toward the front of the boiler. In either case, air can be admitted to the furnace through checkerwork approximating the shape of the flame, to reduce excess air. The area of the openings should be equal to 4 sq. in. per boiler HP. Steam-jet burners should be supplied with dry steam from the top of the auxiliary header. Steam connections should be made for blowing out the oil and steam piping and the ducts in the burner when it is shut down. Strainers in duplicate should be provided in the oil lines. The eight figures in B show arrangements sometimes used for admitting air to oil-fired furnaces through the floor. In No. 1 the whole floor is brick checkerwork and air is admitted uniformly over the entire surface, producing a fan-shaped flame that burns completely, but does not cover all the openings so that excess air enters, reducing economy. Nos. 2, 3 and 4 show air ports near the front, No. 5 transverse openings all over, No. 6 transverse openings at the back only, and No. 7 longitudinal openings—all of these result in localized heating and in soot at other points. Transverse slots, as in No 8, covering approximately the area under the flame, or a fan-shaped area of checker brick, leading out from under the burner, with the rest of the floor solid, give an even flame without excess air.

R F. Burke describes the 700-HP H-type Heine boiler shown in Fig. C, fired with forced-draft mechanical oil burners and designed for an
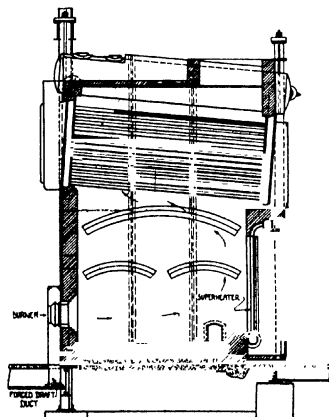
C. FURNACE FOR MECHANICAL OIL BURNERS
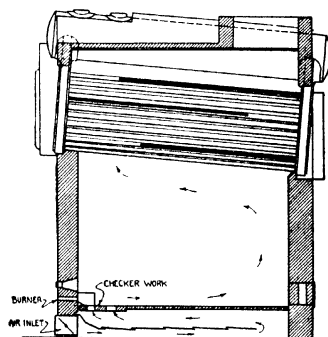
D. FURNACE FOR STEAM-JET OIL BURNERS—*Power Plant Engg.*

ordinary load of 200% and peak loads of 300% of normal rating. A long flame travel is obtained without direct impingement on boiler surfaces, and the gases make a complete turn in the furnace before entering the first boiler pass. Fig. D shows a 600-HP. H-type Heine boiler fired with steam atomizing burners, which showed efficiencies of 80 to 83% from 100 to 200% of rating, and a gross daily efficiency, including economizers, of 84 to 86%.

The drawings, E and F, show the setting and details of the mechanical oil burners used in a 15,000 Kw. plant with boilers of 3500 to 5000 sq. ft. heating surface each, and three to four burners The bottoms of the settings, which were formerly equipped with stokers, were covered over with steel plate, asbestos mill board, nonpareil block, Sil-o-cel and firebricks. Near the feed pumps is a steam-actuated master controller set of the *Merit* type, connected to the main steam header, operating a damper-interlocking device on the front of each battery of boilers, which operates the stack dampers and controls the fire in three predetermined steps by connections to the cutout valves. The first step admits oil through the reducing valve on the right-hand branch of the burner unit at 100 lb. pressure; for intermediate fire it is admitted through the cutoff and reducing valve in the middle branch at 140 lb. pressure, and for maximum fire through the cutoff valve in the left-hand branch at full pump pressure, 160 lb. These three steps give boiler ratings from 50% up to 200 or 250%.
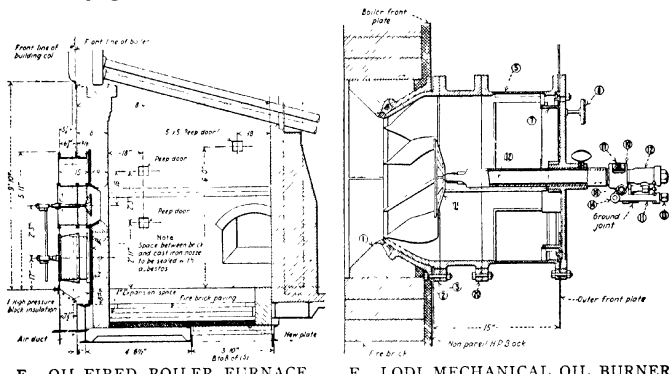
E. OIL-FIRED BOILER FURNACE   F. LODI MECHANICAL OIL BURNER
—*Power.*

Power Plant Engineering describes changes made in the setting for a 600-HP. boiler to permit the use of heavy oil (12 to 14° Baumé) containing considerable free carbon in suspension, in place of high-grade light oil. The original setting employed three burners per boiler, located at point *A*, Fig. G, each with a small arch built over it to prevent air from going straight up along the bridge wall. They were of the outside mixing type, and each one was fed by a ¼-in. oil line inside of a 1-in. steam line, oil being forced out of the upper slot in an almost horizontal plane, while the steam from the lower slot was forced upward on an angle, meeting the

oil spray in a short flat flame. The bridge wall E was removed and the horizontal baffle F extended to the rear wall, which was thickened to 26 in. to protect the mud drum and blow-off lines. Inside-mixing burners, see Figure H, were adopted, in which steam was admitted at B, drawing in oil through C and E. The burners were cut at M, each part being threaded so that they could be separated by a length of pipe, in order that the oil entrance E could be set back and protected from heat which would cause it to be clogged by free carbon. Four burners were used in the improved setting, inserted through openings B, with 17 x 19-in. air openings C under each, and an auxiliary air duct D extending across the furnace, covered by 4 x 12 x 24-in. tile, with 12 openings in the top, and shut-off dampers at the side, for use at light load. In place of needle valves, subject to clogging, fine adjustment of oil flow was effected by using standard steam cocks with V-notches cut in the core and body of the cock. With the new furnace and larger combustion space, the boilers were operated at 200 to 250% of rating, with an average increase of 7% in efficiency.
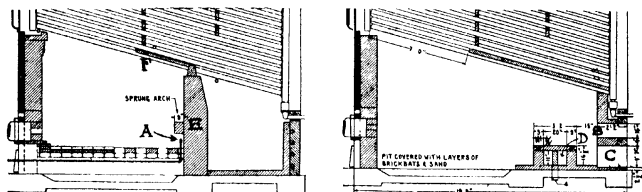
G. SETTING ALTERED FOR FIRING OF HEAVY OIL
—*Power Plant Engg.*

Joseph Pope and *Frank G. Philo* describe an installation in the plant of the Savannah Electric Co., Fig. M, in which efficiencies of 80% were obtained at 300% of rating. The 665-HP. B. & W. boilers are equipped with mechanical atomizing burners designed by the B. & W. Co., which receive the oil at 230° F. and a maximum pressure of 210 lb., delivering it in a whirling cone. The boilers were formerly equipped with stokers, and the old front was replaced by a steel plate blast box containing the burners and forced-draft air registers.
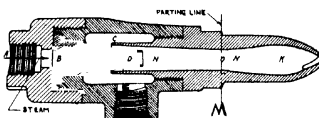
H. INSIDE-MIXING-TYPE BURNER

Fig. J shows a 24,450-sq. ft. boiler at Seal Beach Station, Los Angeles, with the oil-firing front under the downtake header. Special circulating tubes run from the top of the uptake header into the boiler drum to preclude steam binding. The burners are of a special combination type for the burning of either oil or gas. For access to the furnace the oil-burner section can be swung back on hinges. Air heaters are placed in the uptake, with vertical flue-gas tubes, while the air is carried in three passes at right angles to these tubes, heated to 300° F., passed to the forced-draft fan and thence down the side and rear walls and beneath the furnace hearth to the burner front. Oil is heated in three stages, the last heater employing steam at 350 lb. from a desuperheater, and fed to a loop system.
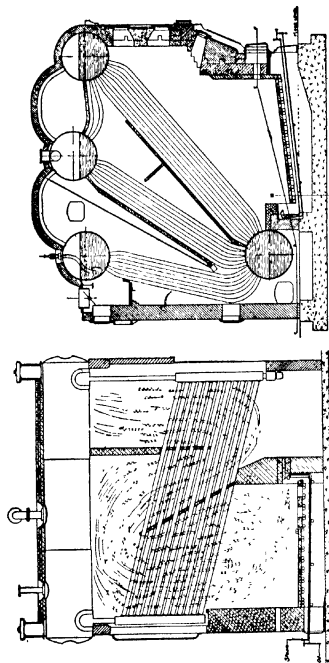
I. HAMMEL BACK SHOT OIL-FIRING SYSTEMS

L. ROGERS-HIGGINS OIL AND BAGASSE FURNACE

K. ROGERS-HIGGINS OIL FURNACE USING PREHEATED AIR
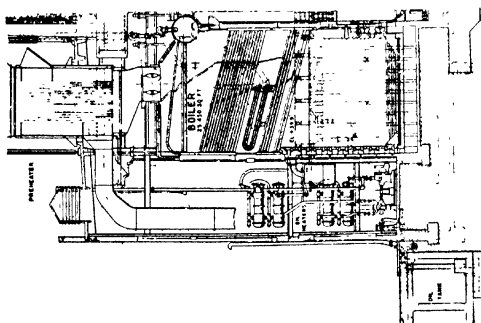
J. SEAL BEACH OIL-FIRED FURNACE—Power Plant Engg
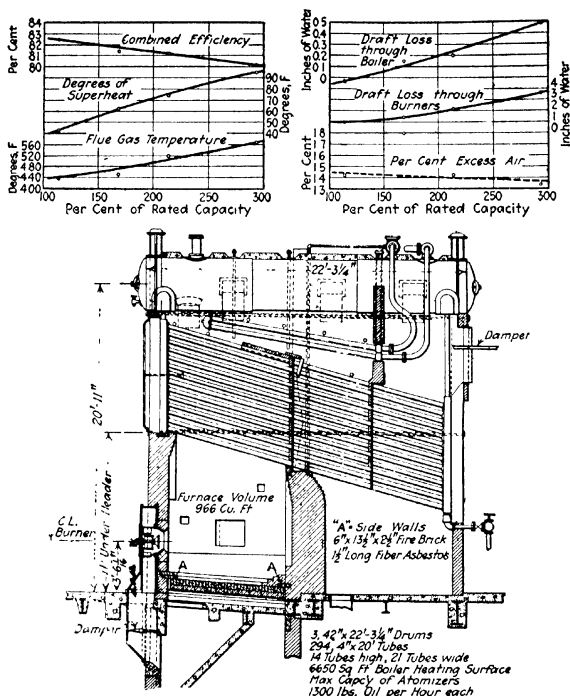
M 665-HP BOILER EQUIPPED WITH B & W. BURNERS
—*Elec. World.*

E. B. *Powell* states that *Stone & Webster* have installed settings in which the ventilating ducts in furnace walls are supplied with air under pressure from the forced-draft fans, which provides more effective cooling of the brickwork than when the ducts are under suction from furnace or fan, and avoids the necessity for high pressure differentials on the walls of the setting beyond the ventilated area. He also describes experiments on two furnaces fired by mechanical burners, the furnaces having approximately equal rectangular horizontal sections and areas of heating surface exposed to direct radiant heat, but of different heights from the floor to heating surface. The smaller furnace had a total refractory surface (including floor) per square foot of exposed heating surface of approximately 3.4 sq. ft. and a volume of approximately 7 cu. ft. per square foot of exposed heating surface—the exposed heating surface being figured as
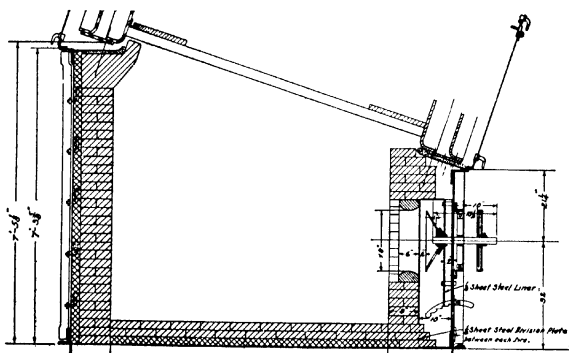
COEN MECHANICAL OIL-FIRING SYSTEM, WATER-TUBE BOILER

a plane surface parallel to the axes of the tubes limited by the four walls of the furnace. The larger furnace had corresponding refractory surface and volume of approximately 5.4 sq. ft. and 10.7 cu. ft., respectively. It had been found that when burning as high as 40 to 45 lb. of oil per sq. ft. of exposed heating surface in each furnace, using the same atomizing pressure of about 175 lb. and the same rate of air supply, about 20% excess over theoretical requirements, maximum flame temperatures of about 2850° to 2900° F. and 2900° to 2950° F. were obtained in the respective furnaces, the corresponding average flame temperatures appearing to be about 150° lower in each case, with the corresponding wall temperatures reaching about 2600° and 2700°, respectively, except that where the hottest flames played against the wall the immediate area might attain temperatures 100° higher than these figures.

A 35% reduction in rate of combustion, if pressure of atomization and ratio of air and fuel remained the same, would in the case of the larger furnace reduce the flame temperature by scarcely 50° and wall temperatures but slightly more, while in the smaller furnace, although the flame temperatures appeared to be lowered only slightly more than 50°, the wall temperatures were reduced by 100° to 150°. Apparently the higher ratio of absorbing surface to radiating surface in the smaller furnace caused the latter to give up heat more readily than in the case of the larger furnace, so that for a given variation in rate of combustion the wall-temperature fluctuations were greater in the smaller furnace.

Refractories.—*E. B. Powell* gives the following grouping of bricks which have given good service in oil-fired furnaces:

1. Bricks of high fusion point and inherently high resistance to spalling.

2. Bricks of high fusing point which, while subject to fracture under conditions of repeated temperature change, were of such highly refractory material that there was no tendency to softening even at the maximum
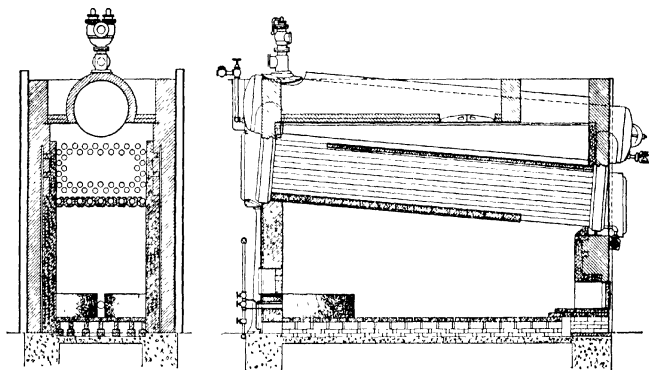
WATER TUBE BOILER EQUIPPED WITH *W. N. BEST* OIL BURNER

temperature of the furnace, so that parts broken off did not become dislodged but remained to serve as a protecting screen for the main body of the brick.

3. Bricks which had comparatively low inherent resistance to spalling and combined with a comparatively low fusing point great tenacity in the semi-plastic state Bricks of this class, if employed within the limits of their safe temperature range, glazed over to form almost monolithic walls and gave a longer life than many bricks of much more highly refractory material. However, such bricks softened rapidly under temperatures but slightly higher than those for which they were best adapted, and should be used with caution where subjected to heavy loading.

Portions of the furnace walls that are subjected to the highest temperature should be relieved of all possible strains and load for the reason that brickwork begins to fail by plastic deformation before it reaches the melting point. The greater the load the lower the temperature at which the wall will fail Arches should be used to sustain the weight of the brickwork above the high temperature zone. This permits the brickwork in the furnace to be repaired more readily and economically and it also increases the life of the furnace brickwork by reducing the pressure on it.

In setting up the fire-brick lining, suitable allowance should be made for expansion at the joints. A cement wash surface will serve to protect the edges and joints, according to *Allen F. Brewer.* This should not be applied until the bricks and mortar have been thoroughly dried by heating and cooled till the walls are comfortable to the touch. Broken glass scattered on the floor will melt on firing up, resulting in a satisfactory glazed bottom.

G. H. Peltz reports that for an 8-in. brick at a furnace temperature of 2700° F., the outside temperature was 800° F. in still air, which a very slight motion of air reduced to 200° F. Air velocities ranging from 50 to 150 ft. per sec. reduced the outside temperature to 20° above room

temperature, but no further. Presumably the longer life of walls cooled on the outside, even when the interior surface is soft and beginning to run, is due to the fact that the cooling further back gives the whole brick sufficient body to keep it from falling to pieces.

Thomas S. Curtis describes Argon AA brick, for use with oil-burning boilers, made from California clays containing one molecule of alumina to two of silica, impurities being removed which tend to promote vitrification accompanied by plasticity of the body of the brick. Such brick will not melt below 3250° F., and will bear a load of 25 lb. per sq. in. at 3000° F. with not more than 10% deformation in a neutral or oxidizing atmosphere, but if saturated with reducing vapors at the same temperature will hardly bear its own weight. It is therefore coated with a refractory crystalline glaze made of sillimanite, which seals the pores but will not drip, cut back and hasten destruction. The face of the wall is tied to the outer support by the use of Tylox, a continuous mechanical interlocking bond between the shell of the boiler setting and the innermost face of the refractory lining, which minimizes the effects of the vibration caused by the pulsation of the oil flame

Chimneys.—*Derby* recommends for oil-fired furnaces 1 sq. ft chimney area for each 400 or 500 sq. ft. of boiler heating surface, and a height ten to fifteen times the diameter, say 100 to 180 ft Sizes recommended by the *Bureau of Mines* are shown in the following table:

Stack Diameter, In.	80	90	Height Above Boiler-room Floor, Ft 100	120	140	160
			Nominal Rated Boiler HP.			
33	161	206	233	270	306	315
36	208	253	295	331	363	387
39	251	303	343	399	488	467
42	295	359	403	474	521	557
48	399	486	551	645	713	760
54	519	634	720	847	933	1,000
60	657	800	913	1,073	1,193	1,280
66	813	993	1,133	1,333	1,480	1,593
72	980	1,206	1,373	1,620	1,807	1,940
84	1,373	1,587	1,933	2,293	2,560	2,767
96	1,833	2,260	2,587	3,087	3,453	3,740
108	2,367	2,920	3,347	4,000	4,483	4,867
120	3,060	3,660	4,207	5,040	5,660	6,160

Storage.—Vertical steel tanks, usually located above ground on concrete foundations, are used for storage of large quantities of oil in open surroundings, while horizontal steel tanks are used above or below ground for less than 400-barrel storage. Concrete tanks are less costly, have a lower fire hazard, are free of corrosion, and are built in rectangular, cylindrical and elliptical shapes. The table by *Allen F. Brewer* gives the common sizes and capacities. The top of any underground tank should be set below the level of the lowest distribution tank of the system, to prevent flooding in case of valve failure, and should be at least three feet below ground and five feet from the building line.

OIL-STORAGE TANK CAPACITIES

Vertical Steel Tanks		
Diam., Ft.	Height, Ft.	Capacity, Bbl of 42 Gal.
52	35	13 600
52	30	11,700
42	30	7,800
42	25	6,500
38	25	5,000
30	35	4,400
28	35	4 000
30	30	3,770
28	30	3,450
30	25	3,140
25	30	2,620
23	30	2,400
23	25	2,000
23	20	1,750
20	25	1,400
20	20	1,100
19	15	800
15	20	630
15	15	470

Horizontal Steel Tanks			
Diam , Ft.	Length, Ft In		Capacity, Bbl of 42 Gal.
6	21	5	107
6	29	11	151
7	25	8	175
7	29	11	203
8	25	8	230
8	29	11	267
9	25	8	291
10	25	8	359
10	29	11	418

Reinforced Concrete Tanks

Dimensions, Ft	Shape	Capacity, Bbl of 42 Gal.
16 x 10	Round	360
45 x 16	Round	4,330
63 x 11	Round	5 240
125 x 12	Round	23,800
72 x 72 x 10	Square	10,710
20 x 10 x 10	Rectangular	380
29 x 14 x 10	Rectangular	710
68 x 21 x 21	Rectangular	5,120

Gravity supply from pump to burners is not ordinarily permitted and duplicate pumps of the horizontal, duplex, cross-connected, steam-driven, piston type should be used, each capable of handling the maximum load. The suction pipe should be short, free of fittings and insulated if overground. A standpipe or air chamber in the oil line from pump to heater will smooth out pulsations in flow. *Parker* recommends rotary pumps for use with mechanical burners, as producing less fluctuation in pressure.

SIZES OF FUEL-OIL PUMPS WITH APPROXIMATE CAPACITIES—*Brewer*

Size, In.	Approximate Boiler-Heating Surface per Pump*	Normal Max Pump Capacity	
		Gal per Min	R P.M.†
3x2x3	4,000	5-8	55
3½x2¼x4	6,000	8-12	50
4½x2¾x4	10,000	12-20	50
5¼x3½x5	25,000	20-35	45
6x4x6	40,000	35-50	40
7½x5x6	75,000	50-80	40
9x5¼x10	100,000	80-125	35

*For an oil below 18° Baumé gravity   †Rated normal maximum
With an average evaporation of 14 lb water per pound of fuel oil, there will be required about ½ gal. of oil per min. per 1,000 sq ft boiler-heating surface   When an extra heavy oil is to be used—that is, below 12° Baumé gravity—it is well to select the next larger size of pump than the one commonly required

Heaters, employing live or exhaust steam, are essential to a free flow of oil of reduced viscosity to the burners   They may be independent or constructed as integral parts of the oil pumps.   The endless coil within a receiver, the double-pipe coil, and the straight-pipe, return-tubular coil within a receiver, are used. *Brewer* gives the following table of recommended heater sizes.

HEATING SURFACE VS. CAPACITY OF FUEL-OIL HEATERS

Approx. Sq. Ft. Boiler Heating Surface	Approx Sq Ft of Oil Heating Surface Required*	Approx Normal Maximum Gal per Min Passing Through Heater
4,000	15-20	5-8
6,000	20-25	8-12
10,000	25-40	12-20
25,000	40-50	20-35
40,000	50-100	35-50
75,000	100-150	50-80
100,000	150-200	80-125

*Depending on grade and gravity of oil, heavier oils will require somewhat more heating surface.

Frank G. Parker recommends a temperature of at least 150° F. in the oil going to a steam atomizing burner, even though additional heat is imparted by the steam, and suggests a pump pressure of 75 to 125 lb. for oil up to 18° B. With mechanical burners, the temperature should be sufficient to reduce the viscosity to 8° Engler, and too low a temperature will cause the burners to smoke heavily. One manufacturer recommends the following temperatures for his burners. These should be applicable to all makes of mechanical atomizing burners.

° Baumé	Minimum Temperature, ° F.
24 to 30	80 to 100
20 to 24	100 to 140
17 to 20...	140 to 160
15 to 17....	180 to 190
13 to 15..................	200 to 220
11 to 13...........	240 to 270

Strainers on the suction side of the pump are useful for the protection of the latter, and the mesh should not be less than 16 per inch, while the discharge strainers, which *must* be used, should have a mesh not less than 40 per inch.

Brewer gives the following formula for **oil velocity in the pipes** from the heaters:

$$v^2 = 200,000/E$$

where v is velocity in ft. per min., and E is viscosity in ° Engler. In marine practice, oil is heated to reduce it to a viscosity of 10° Engler. For stationary practice, where 20° is often considered sufficiently fluid, this gives a recommended oil velocity of 100 ft. per min.

The pipe diameter, in inches, $= 4.1\sqrt{(B/v)}$, where B is the flow in barrels per hr. With an evaporation of 14 lb. water per lb. of oil, about ½ gal. of oil (1/84 of a bbl.) will be required per min. per 1000 sq. ft. boiler heating surface. For 25 bbl. oil per hr., and velocity 100 ft. per min., the above formula gives 2 in. as the pipe diameter.

The oil distribution piping should be installed without dead ends, preferably in accordance with return-circulating principles; thus oil will be flowing at all times, deposits in the line will be decreased, and the oil will retain its heat better, while the heat contained by the surplus oil can be utilized in heating the oil drawn from the storage tank. In operation, oil-distribution lines should be blown out with high-pressure steam at regular intervals to insure clean pipes and prevent deposits.

The size of the oil-distribution lines from the oil header to the burners can safely be taken, in practically all cases, at ⅜- to ½-in. To an extent this will depend on the number of burners in use; and, as a general rule, the total area of oil-burner piping should approximately equal the area of the oil header. Steam-header piping to burners can be taken at about two sizes less than the oil header, the lines to each burner being the same size as the oil-burner piping.

A fuel-oil meter serves as a check, even though the storage tanks are gaged, and piston- or rotary-type instruments register within 1% accuracy.

FUEL-OIL METER SIZES, WITH APPROXIMATE CAPACITIES AND BOILER
HP. SERVED.—*Brewer*

Size, In.	*Approx Normal Maximum Flow in Gal per Hr	†Approx Maximum Boiler Heating Surface Capable of Being Served, Sq Ft
⅝	300	10 000
¾	600	20 000
1	900	30,000
1½	1,500	50,000
2	2,400	80,000
3	4,200	120 000

*To a certain extent this will depend on the grade of oil, its viscosity and the degree to which it is heated before metering

†Based on an average fuel consumption of one-half gallon per minute per 1,000 sq. ft boiler-heating surface, at an average evaporation of 14 lb of water per lb. of oil fired.
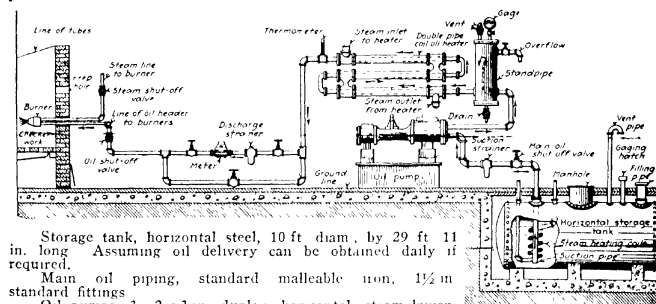
Storage tank, horizontal, steel, 10 ft diam, by 29 ft 11 in. long Assuming oil delivery can be obtained daily if required.
Main oil piping, standard malleable iron, 1½ in standard fittings
Oil pumps, 3 x 2 x 3-in duplex, horizontal, steam-driven, installed in duplicate
Oil heater, three 20-ft lengths of standard malleable iron 2 and 3-in. pipe to form a double-pipe coil, standard ammonia fittings used on ends; 18 sq. ft. of heating surface. Oil capacity 5 to 8 gal per min
Meter, standard ⅝-in type
Number of burners, depends on number of boilers installed Usually one burner per boiler; or, if more than one burner, use one burner per 2,000 sq. ft heating surface.

EQUIPMENT FOR A 4,000 SQ FT BOILER OIL-BURNING INSTALLATION
—*Power.*

The above figure, by *Brewer*, exhibits the basic elements of a typical fuel-oil burning installation, but does not show steam lines, governor, etc., nor the return oil line.

H. E. Newell states that the storage of oil in outside underground tanks is safest because of the absence of hazard from lightning and breakage of pipes or rupture of the tank. With tanks buried beneath buildings, there is the danger of oil and vapor escaping into the building during filling, but this hazard is not deemed material. Tanks *inside* buildings must be protected against the danger of falling walls incidental to large fires, and insulated against furnace heat, using enclosures of reinforced concrete, with sand as insulator between concrete and tank shell. Such tanks are fairly safe and have not been involved in any serious fires. Outdoor above-ground tanks with wooden tops are subject to lightning hazard, but vapor-tight all-metal tanks, properly riveted, vented and grounded, with joints so made as to eliminate the possibility of sparking during static discharges, are practically immune, until the joints work loose from expansion strains. To take care of oil boiling over under fire conditions, tanks should be surrounded with dikes large enough to contain 1½ times the tank capacity. A weak joint between roof and walls is not recommended for the relief of pressure—modern practice calls for gas tightness and adequate venting. In addition to venting for breather requirements and outflow of air in filling, the covers of openings for gaging purposes and manhole covers should be held in place by weight only. With adequate venting facilities, the tank, instead of exploding when exposed to fire, will act as a still and give off vapor, which may burn at the vent opening. Unless the tank foundation is naturally grounded, copper rods or wires should be bonded to the tank and extended to a point of permanent moisture. A screen of 40 by 40 mesh on small vent pipes will prevent flame from passing to the tank interior; arresters consisting of a bank of tubes are of value on openings larger than six inches in diameter.

For low-pressure oil systems the piping should be of standard full-weight wrought-iron or steel, for working pressures in excess of 100 lb. "extra-heavy" piping and fittings are required. Piping should be run as directly as possible without sags and so laid that, where possible, pipes pitch back to the supply tank without traps; provision should also be made for expansion, contraction, jarring and vibration, and the job should be tested at 50% excess pressure, with a minimum of 150 lb. Connections should in general be at top of tank. Piping should be laid in a trench with metal cover, not containing lines for oxygen or for fuel gases, and where the piping passes under buildings it should be enclosed in open-end pipes so that leakage will be discovered. Indoors it should be protected from injury and jarring, especially at risers. The oil pump should be where it can be shut down without entering the boiler room, as by remote control, and the room should be fire-resistant. Rotary oil pumps, when used, should be geared to same shaft as the blower, and an expansion chamber and relief valve on the discharge with drains to the storage tank are of value in regulating flow, with a by-pass around the pump to permit piping to drain to storage tank. A basket strainer should be used on suction side of the pump, with a single gage connected to show the pressure drop and give warning of dirty strainers. If finer than 8-mesh is used, the pump may be overloaded and lose suction. Burners other than mechanical atomizing type should be so designed as to make impossible the enlarging of discharge orifice and so arranged that the needle valve cannot be unscrewed and removed in operation. Burners should be properly supported, if necessary, independently of the piping, and should be cleaned in kerosene when fouled. Gravity flow from storage to burners is not permitted, but National Board

rules permit gravity flow from main storage to a service tank by a normally-broken connection safeguarding against gravity flow or siphonage from main storage to burners, the supply being pumped from the service tank to the burners.

Due largely to the absence of combustible-in-ash losses, efficiencies for different periods under the same general conditions will be found to be almost exactly proportional to the factor $\dfrac{T-t}{\%\,CO_2}$, where $T-t$ is the temperature difference between flue and boiler room. Pyrometer and CO_2 observations therefore give a very satisfactory gage of oil-burner operation, or even the CO_2 readings alone, as flue temperatures are generally nearly constant.

Fig. A, p. 461, indicates the numerical relation between CO_2 readings and excess air for fuel oils of various compositions. Sulphur is considered in the calculation of the C/H ratio because it burns to SO_2, which is included in the CO_2 reading of the gas analyzer. For the higher hydrogen fuels (lower C/H ratio) there is a larger proportion of water vapor formed, and a smaller CO_2 percentage for the same excess air, hence the dip of the curves at the left-hand side.

For this reason a given CO_2 content in gas from oil burners implies less excess air than does the same reading from coal furnaces, but oils are susceptible to burning with such small quantities of excess that 12 to 15% CO_2 is easily secured.

AIR REQUIRED FOR OIL BURNING—$C\ R\ Weymouth$

% CO_2 by Volume of Dry Gases	Light Oil*		Medium Oil*		Heavy Oil*	
	Lb. of Air per Lb. of Oil	Excess Air %	Lb. of Air per Lb. of Oil	Excess Air %	Lb. of Air per Lb. of Oil	Excess Air %
4	51.40	260.7	51 93	270 4	52.45	280.3
5	41.31	189.9	41.71	197 5	42 12	205.4
6	34.58	142.7	34.90	149.0	35.23	155.4
7	29.77	108 9	30 04	114 3	30.31	119.8
8	26.17	83 6	26.39	88 3	26.62	93.0
9	23.37	64.0	23.56	68.0	23 75	72.2
10	21.12	48.2	21 29	51 8	21.45	55.5
11	19 83	39.1	19 43	38 6	19.58	41.9
12	17.76	24.6	17.88	27.6	18.01	30.6
13	16.46	15 5	16.57	18.2	16.69	21.0
14	15.36	7 8	15.45	10.2	15.55	12.7
15	14.39	1.0	14.48	3.3	14.57	5.6

*Composition as in table on page 461.

Operation of Oil Burners. Fires are started by turning on the draft and the pump, and then placing a torch in front of the burner and turning on the oil. It is particularly important not to admit any oil to a "dark" furnace, as it may form an explosive mixture.

Great care must be used to regulate the air supply properly. Although it is much easier to operate an oil-burning installation day in and day out at test-condition efficiencies than it is a coal-burning furnace, it is also possible to get very low efficiency and still keep the fire going. With coal, if conditions are too much neglected, it becomes impossible

to keep up steam. A dazzling white flame may indicate too much air. It certainly should not extend back more than 6 inches from the burner, beyond which it usually becomes transparent, runs into violet, and toward the end changes to red. With too little air, no violet is seen, the red darkens, and smoke appears. Streaks in the flame indicate dirty tips.

It is generally conceded that the appearance of the stack is a useful gage of the correctness of operation. Smoke of course indicates deficiency of air, and a good rule is to increase the air until only a very slight haze is seen escaping, which indicates the absence of undue excess air. No difficulty should be experienced in maintaining 13 to 14% CO_2, using about 250 cu. ft. of air per lb. of oil, representing 10% excess.

It is very easy to waste steam for atomizing. *F. W. Small* suggests the use of a by-pass, the valve in the main pipe being arranged to supply steam at a maximum rate of 1%. This suffices for driving the boiler at normal rating, but when it is forced, the by-pass is used to obtain additional steam, and anyone entering the boiler room can tell if it is being opened unnecessarily.

Vibration of burners can be eliminated by increasing the air supply and velocity, or temporarily cutting the supply of oil to the troublesome burner. The draft is best controlled by the damper, with little or no draft in the combustion chamber, giving natural travel of the gases and minimum air leakage

If the furnace volume is too small for high ratings and continuity of service is required, the excess air should be increased, as 1% drop in CO_2 will shorten the flame several feet and prevent impingement and soaking of oil into the brickwork.

H. E. Newell calls attention to the fact that when starting up a new oil system, or after a long period of idleness, care should be exercised to insure that the system is free from waste, flakes of shellac, red lead, and dirt, by thoroughly blowing through with air. All strainers should be cleaned and any wire mesh found to be defective, removed. Cleanliness of atomizing tips and other parts of burners should be insured and they should be properly adjusted in the air registers. The latter should be tested out to insure their working condition Individual control valves to each burner should be closed. If air chambers are fitted on the oil lines they should be drained and then charged with compressed air. Valves in pump suction lines should be opened. Blowers should be warmed up and ready to turn over. In lighting, a hand torch should be used, the fireman standing well away in order to avoid a flareback. No matter how hot the furnace may be, if all burners are temporarily out, no effort should be made to relight from the incandescent brickwork. A suitable lighting torch may be made by securing on the end of a rigid wire rod about 2½ or 3 ft. in length a few loose ends of asbestos wicking which may be dipped in oil. Every precaution should be taken to prevent unburnt oil from collecting in the furnace, as the hot brick gasifies it and there is serious danger of a violent explosion. A flareback is caused by an explosion of a mixture of oil and vapor or gas and air in the furnace. Such an explosion may cause grave injury to the burner, boiler, and attachments. It is most likely to occur in lighting up or in attempting to relight an atomizer or burner from a hot brick wall. To prevent flarebacks: (a) do not permit oil to accumulate in the furnace. Oil on furnace floor should be wiped up and the furnace blown through with steam or air before lighting the burners. Burner control valves must be kept tight at all times to prevent leakage

Carbon-Hydrogen Ratio in Moisture-free Fuel

Per Cent available Hydrogen in Combustible
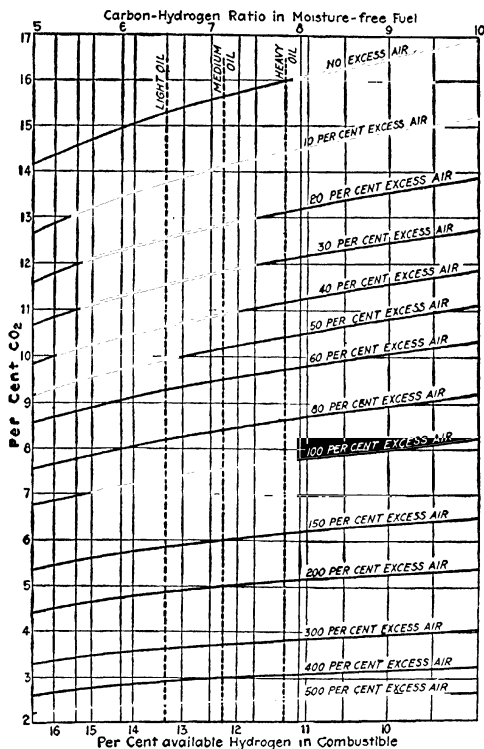
A. RELATION OF CO_2 TO EXCESS AIR FOR FUELS CONTAINING HYDROGEN

$$C\text{-}H \text{ ratio} = \frac{C + 0.4\ S}{H}$$

$$\%\ \text{available}\ H = \frac{100\ H}{H + C + 0.4\ S}$$

C, H & S representing percentage by moisture-free analysis.

APPROXIMATE ANALYSIS OF TYPICAL OILS REPRESENTED ABOVE

	C	H	S	N	O	H_2O
Light	84	13	0.8	0.2	1	1
Medium	85	12	0.8	0.2	1	1
Heavy	86	11	0.8	0.2	1	1

—Power.

of oil into the furnace; (b) whenever burners are accidentally extinguished, shut off the oil and blow through the furnace with steam or air before relighting; (c) if a flareback occurs, close the master oil valve shutting off all oil to the furnace; (d) speed up the blowers if in operation, and shut down oil pumps.

Serious hazard arises if dampers in the flues to the stacks are closed or induction fans are inoperative at the time the oil is being ignited, and the operator must assure himself positively that all vents are clear and open before starting the fire. During operation care should be exercised that atomizers or burners are never left disconnected; the operating cock or valve might be unintentionally opened, which would result in oil running into the boiler room with disastrous effects. The temperature of fuel oil should never be raised to or above the flash point in any part of the system except between the pre-heater and the atomizers or burners. The more viscous the oil, the more necessary is it to reduce the viscosity to a low point to obtain good atomization, and the more difficult is it to do so. To obtain the best combustion, it may possibly require heating the oil to a temperature high above the flash point, which is deemed a dangerous expedient unless extreme care is taken to guard against leaks in the oil lines. Every member of the boiler-house force should be thoroughly acquainted with the operation and purpose of all equipment, and know the location and the proper manipulation of all valves and manifolds even when the room is in darkness.

The following fire record was compiled by the *National Fire Protection Association* in July, 1918:

Causes	No of Fires
Broken pipes	26
Broken and defective fittings and valves	12
Carelessness with valves	11
Overheated oil furnaces	7
Miscellaneous carelessness	7
Broken and defective burners and burner connections	5
Leaking pipes	5
Sparks of flames from oil furnaces	5
Explosions in furnaces	4
Clogging of pipes, obstructions to burners	4
Oil getting into air pipes	3
Defective or improperly installed tanks	3
Explosions in tanks	2
Oil soot ignited in flue	1
Data lacking	7
Total	102

Safety.—The 1924 and 1925 reports of the *National Fire Protection Association* include the following regulations governing the use of fuel oil having flash point over 150° F :

Storage of flammable liquids should be outside buildings, in underground tanks or above-ground tanks, except that tanks above ground or outside buildings should not be permitted in congested districts or near streams which would carry liquid into congested districts. Tanks buried underground shall have the top of the tank not less than 2 ft. below the surface of the ground, and below the level of any piping to

which the tanks may be connected, except that, in lieu of the 2-ft. cover, tanks may be buried under 12 in. of earth and a cover of reinforced concrete at least 6 in. in thickness provided, which shall extend at least one foot beyond the outline of tank in all directions; concrete cover to be placed on a firm, well tamped earth foundation. Where necessary to prevent floating, tanks shall be securely anchored or weighted. Where a tank cannot be entirely buried, it shall be covered over with earth to a depth of at least 2 ft., with a slope on all sides not steeper than 1½ ft. horizontal to 1 ft. vertical.

Underground Tanks.   Tanks shall be constructed of galvanized steel, of open-hearth steel or of wrought iron of a thickness not less than that specified.   For liquids heavier than 35° Baumé, tanks may be constructed of concrete in accordance with the Regulations of the *National Fire Protection Association.*

UNDERGROUND STORAGE TANKS

	Capacity (Gal.)		Minimum Thickness of Material Gage (U S Standard)	Weight Lb. per Sq Ft
1	to	285	16	2 50
286	to	560	14	3 125
561	to	1100	12	4.375
1101	to	4000	7	7 50
4001	to	12000	¼ in	10 00
12001	to	20000	5⁄16 in	12 50
20001	to	30000	⅜ in.	15.00

For tanks of 1100 gal. and more a tolerance of 10% in capacity shall be allowed. Tanks of open hearth steel or wrought iron thinner than No 7 gage shall be galvanized.

If adequate internal bracing is provided tanks from 12.001 to 30,000 gal. capacity may be built of steel plate ¼ in. thick. Shells of tanks shall be properly reinforced where connections are made, and all connections made through the top of the tank above the liquid level. Tanks for systems under pressure shall be designed for four times the maximum working pressure, and tested to twice the maximum working pressure. All iron or steel tanks shall be thoroughly coated on the outside with tar, asphaltum or other suitable rust resisting material   Where soil contains corrosive substances, such special protection shall be provided as may be required by the Chief of the Fire Department.

LOCATION OF UNDERGROUND TANKS

	Capacity, Gal.
If top of tank is lower than all floors, basements, cellars, or pits of all buildings.	
a. Within a radius of 50 ft.	Unlimited
b. " " " " 40 "	500 000
c " " " " 30 "	200 000
d. " " " " 25 "	150,000
e. " " " " 20 "	100,000
f. " " " " 10 "	75,000
g If within 10 ft of any building, and the top of tank is above the lowest floor, basement, cellar or pit of the building.	50 000

Tank located beneath a building shall be below all portions of that building and is limited in capacity only in respect to other buildings as given above under *a* to *g.* A tolerance of 10% in capacity shall be allowed in tanks of 150,000 gallons or less capacity.

For tanks over 400,000 gal. capacity, a minimum distance of 175 ft. to adjoining property or nearest building may be permitted, provided that an approved type of extinguishing system is installed for the tank and covering other parts of the yard. For tanks permitted from 50 ft. and up to 175 ft. of building or property line, the capacity may be increased 33% if the tank is provided with an approved extinguishing system.

Above-Ground Tanks.—Tanks (including tops) shall be constructed throughout of open-hearth steel or of wrought iron of a thickness in accordance with the following requirements. No open tank shall be used. For liquids of 35° Baumé or heavier, tanks may be constructed of concrete in accordance with the Regulations of the *National Fire Protection Association.*

HORIZONTAL OR VERTICAL TANKS NOT OVER 1100 GAL. CAPACITY

Capacity (Gal)	Minimum Thickness of Material
1 to 60	18 gage (U. S. Std.)
61 to 350	16 gage "
351 to 560	14 gage "
561 to 1100	12 gage "

Horizontal tanks over 1100 gal capacity shall be of such material and so constructed as to have a factor of safety of at least 2 5 with hydrostatic head figured with water. The minimum thickness of shell or head shall be ¾₆ in (No 7 gage, U. S. Standard). The thickness of shell plates shall be in accordance with the following formula:

$$t = \frac{P \times r \times F}{T \times E}$$

Where t = thickness of plate in in
P = working pressure in lb. per sq. in.
r = radius of shell (inside) in in
F = factor of safety (taken as 2 5)
T = tensile strength of plate in lb per sq in.
E = efficiency of longitudinal riveted joints.

Vertical tanks over 1100 gal capacity shall be of such material and so constructed as to have a factor of safety of at least 2 5 The minimum thickness of shell or bottom shall be ¾₆ in The minimum thickness of roof shall be ⅛ in The thickness of plates shall be in accordance with the following formula:

$$t = \frac{2\,604 \times H \times D \times F \times S}{T \times E}$$

Where H = height of tank in ft above the bottom of the ring under consideration.
D = diameter of the tank in ft.
S = specific gravity of liquid stored (water = 1).
E = Efficiency of vertical joint in ring under consideration.

The tensile strength of the steel shall be taken as 55,000 lb per sq. in. and the shearing strength of rivets shall be taken as 40,000 lb. per sq. in.

LOCATION OF OUTSIDE ABOVE-GROUND TANKS*

Capacity of Tank, Gal.	Minimum Distance of Tanks to line of adjoining property which may be built upon*	Capacity of Tank (or of the larger of the two tanks between which distance is to be measured) Gal.	Minimum Distance Between Tanks, ft.
800 or less	5 feet	18,000 or less	3 feet
1,300 "	10 "	24,000 "	5 "
2,600 "	20 "	48,000 "	10 "
21,300 "	25 "	75,000 "	13 "
32,000 "	30 "	100,000 "	15 "
48,000 "	40 "		
64,000 "	50 "		
80,000 "	60 "	Above 100,000—Dist. equal to diam. or	
128,000 "	75 "	greatest horz. dimension	
200,000 "	85 "	of larger tank.	
266,000 "	100 "		
400,000 "	150 "		
666.000 "	250 "		
1,333,000 "	300 "		
2 666,000 "	350 "		
Unlimited	400 "		

*This table is being considered by a special committee with a view to revision of the distance requirements.

Each above-ground tank, inside or outside buildings, over 1,000 gal. in capacity, shall have all manholes, hand holes, vent openings and other openings, which may permit the escape of flammable vapor, provided with a non-corrodible wire screen (preferably 40 x40 mesh but not less than 30 x 30 mesh or its equivalent), so attached as to completely cover the opening and be protected against clogging. A safety valve shall be provided, or manhole covers shall be kept closed by weight only, and not firmly attached. The screens on openings may be made removable, but shall be kept normally firmly attached

All iron or steel tanks shall be thoroughly coated on the outside with tar, asphaltum or other suitable rust-resisting materials. Roofs or tops of tanks shall have no unprotected openings. Roofs or tops shall be firmly and permanently joined to the tank and all joints shall be riveted and caulked, brazed, welded, or made tight by other process satisfactory to the Chief of the Fire Department. With the approval of the Chief of the Fire Department, tanks of copper or other suitable material may be used if after the necessary handling incident to installation, they are equivalent in strength, rigidity, durability and tightness to the steel or iron tanks described above. Tanks shall safely sustain a hydrostatic test at least double the pressure to which they may be subjected. Top of tank shall be securely fastened to top ring, with joints equal to those between rings. All pipe connections shall be made through flanges or metal reinforcements securely riveted, welded or bolted to the tank and shall be made thoroughly tight. Tanks shall be constructed entirely of metal, including top, sides and bottom, all openings shall be gas tight, except breather vent which shall be screened as provided above. All tanks shall be electrically grounded by resting directly on moist earth or otherwise electrically grounded to permanent moisture to the satisfaction of the Chief of the Fire Department. No insulated connections shall be permitted. Telephone poles or other projections liable to act as lightning discharge points shall be kept as far as practicable from tanks. All steel work of reinforced concrete tanks shall be interconnected and grounded by an approved method. Tanks more than one foot above the ground shall have foundation and supports of non-combustible materials, except that wooden cushions may be permitted, no combustible material shall be permitted under or within ten ft of any above-ground outside storage tank.

In locations where above-ground tanks are liable in case of breakage or overflow to endanger surrounding property each tank shall be protected by an embankment or dike. Embankments or dikes shall be constructed of earthwork, clay core with cinder-fill, masonry, or concrete, approved by the Chief of the Fire Department. Such dikes, when constructed of earthwork or clay core with cinder-fill, shall have a capacity at least one and one-half times that of the tanks. When constructed of masonry or concrete dikes shall have a capacity at least equivalent to that of the tank. Earthwork embankments shall be firmly and compactly built of good earth from which stones and vegetable matter have been removed. Earthwork embankments shall have a flat section at the top of not less than three feet and shall have a slope not steeper than 1½ ft horizontal to 1 ft vertical on both sides. Small tanks with capacities of not over 25,000 gal. each may be grouped and a dike built around the group of tanks.

Stationary Tanks in Buildings—Tanks of 120 gal or less capacity shall be of galvanized steel or tin plate, suitable for the purpose, with all joints locked, double seamed or riveted and also soldered or made tight by some equally satisfactory method; material shall be of not less than No 20 gage U. S Standard, except that where used in connection with and in the same room with oil burning equipment No. 16 gage metal shall be used. Original barrels or drums may be used until contents are drawn, if substantially placed to prevent tipping or rolling, with pump inserted through a close-fitting connection in side or head. Tanks greater than 120 gal. capacity shall be of thickness specified for underground tanks, or of concrete, and shall be vented as specified below. Tanks shall be located below the level of any piping to which they may be connected, or if this is impracticable, arrangements satisfactory to the Chief of the Fire Department shall be made to prevent siphoning or gravity flow in case of accident to the equipment or piping. Tanks shall be set on a firm foundation and those exceeding 2500 gal. capacity shall be supported independently of the floor construction. Steel tanks exceeding 250 gal capacity and installed in connection with oil burning equipments shall be completely enclosed with a heat insulation equivalent to reinforced concrete not less than 12 in. in thickness, with at least a 6-in. space on sides between tank and concrete insulation filled with sand or well tamped earth, and with 12 in. of sand on top of tank, either between tank and concrete slab or above concrete slab. Concrete tanks shall be completely enclosed with a heat insulation of reinforced concrete not less than 8 in. in thickness, with at least a 6-in. space on sides between tank and concrete insulations filled with sand

or well tamped earth, except that for top of tank an insulation of 12 in. of sand without concrete covering shall be deemed sufficient. Walls of concrete tanks shall be constructed independently of and not in contact with the building walls. In ordinary buildings the gross capacity of tanks shall not exceed 5,000 gal. In fire-resistive buildings the gross capacity of tanks shall not exceed 10,000 gal. In any building, if in a fire resistive or detached room cut off vertically and horizontally in an approved manner from other floors of the main building, the gross capacity of tanks may be not exceeding 50,000 gal., with an individual tank capacity not exceeding 25,000 gal., provided the insulating sand specified shall be increased to 12 in. on sides and 18 in. on top.

Piping.—Cross connections permitting gravity flow from one tank to another shall be prohibited except in the case of outside tanks, where this may be permitted through an open connection. All piping shall be of standard full weight wrought iron or steel pipe for working pressure less than 100 lb.; for working pressures in excess of 100 lb. extra-heavy pipe and fittings shall be used. No pipe less than one-half inch internal diameter will be permitted. Piping shall be run as directly as possible without sags and so laid that where possible pipes pitch toward the supply tank without traps; provision shall be made for expansion, contraction, jarring and vibration. All connections of air lines to burners shall be made on the upper side and shall extend upward for a distance of at least 12 in.

Piping after installation shall be tested and proven tight at the following pressures:

Working Pressure	Test Pressure
0-10 lb.	20 lb.
10-100 lb.	150 lb.
Above 100 lb.	50% in excess of working pressure

Test shall continue for 30 minutes.

No right-and-left couplings shall be used, and unions shall be of an approved type. Piping between any separate oil-containing or using part of the equipment shall be as far as practicable laid outside of the building, underground, and properly protected against corrosive action; if necessarily inside it shall preferably be laid in a trench with proper metal cover; if on floor or subject to mechanical injury, it shall be protected. Pipes leading to the surface of the ground or above the floor, particularly risers to furnaces, shall be protected against injury *and rigidly supported to prevent vibration.* Fill and vent pipe shall also be protected. Riser pipes from the oil supply lines to burner fittings shall be not less than 1 in. in size. All outside piping shall be laid in solid earth, or in a trench. Oil pipes shall not be located near nor in the same trench with other piping, excepting steam lines for heating. Propping the pipes on wooden blocks shall be avoided. Openings for pipe through outside walls below the ground level shall be made oil-tight and securely packed with flexible material.

All valves shall be of an approved type. *Where strainers and pump are not a part of a burner unit* shut off valves shall be provided on both sides of any strainer which may be installed in pipe lines; in discharge and suction lines to pump; in branch lines near burners. An outside readily accessible valve shall be provided on all supply lines entering buildings. In installations where pump is located at a distance from the burners, it is advised that a remote control device be installed so that the supply of oil can be cut off at pump in case of accident. *In systems where burner, pump and strainer are assembled as a unit a suitable shut-off valve shall be provided on the inlet side of the strainer.* A check valve of an approved type shall be installed in each air line where an enclosed type of burner is used. A pressure relief valve shall be installed in supply line to burners and so arranged as to return surplus oil to supply tank. The use of automatic shut-off valves for the oil supply is recommended. In systems where either steam or air is used for atomizing, the oil and atomizing supply shall be interlocked in an approved manner so that in case of interruption of the atomizing supply, the oil will immediately be cut off.

A test well or gaging device shall be installed, and so designed as to prevent the escape of oil or vapor *when closed.* Top of well *or gaging device* shall be kept locked when not in use. Suitable strainers shall be installed in the suction line. Large basket strainers are recommended in the receiving or filling line of storage tank to remove dirt and foreign matter.

Heating.—Where it is necessary to heat oil in storage tanks in order to handle it, the oil shall not be heated to a temperature higher than 40° F. below the flash point, closed cup. Heating shall be done by means of properly installed coils within the tank, using only steam or water. Thermostatic control and thermometer shall be provided for all heating devices. Heaters, other than those for tanks, shall be of

substantial construction; all joints shall be made oil-tight. Only steam, water or approved electrical heaters shall be used for preheating. Heater shall be by-passed so that in warm weather it will not be under constant pressure while not in use.

The *burner* mechanism shall be so designed as to not enlarge the orifice, and so that the needle valve cannot be unscrewed and removed in operating. The burner shall be properly supported, if necessary independently of the piping. Attention is called to the serious hazard arising should dampers in the flues to the stacks be closed or induction fans be inoperative at the time the oil is being ignited. Owing to the liability of explosion the operator must assure himself positively that all vents are clear and open before starting the fire.

Pumps.—Oil shall be pumped from tank to burners. Systems where burners are supplied by gravity or pressure on tank shall be in duplicate. Pumps shall be in duplicate, of an approved design, and secure against leaks. They shall be located in a room cut off from oil burning devices and provided with entrance which can be reached without passing through room where burners are located; if this is not practicable, provision shall be made for remote control. Pumps used in connection with the supply and discharge of storage tanks shall be located outside embankment walls, and at such a point that they will be accessible at all times, even if the oil in the tank or reservoir should be on fire. The contractor installing the fuel oil equipment shall furnish copies of diagrams showing all of the main oil lines and controlling valves, and these diagrams shall be posted where the oil system is installed, and also at some other point which will be accessible in case of fire where the fuel oil equipment is located. *It is recommended that approved extinguishing devices of a type suitable for use on oil fires should be provided in connection with oil burning equipments. These should be hand extinguishers or wheeled extinguishers, depending on the size of the equipment.*

Combination Burner.—The *Koerting* burner shown in Fig. B can be used for burning producer or natural gas in conjunction with tar or oil. The liquid is admitted through *OS,* and the gas through *HA,* forming an intimate combustible mixture. Combustion air is admitted through an adjustable air register, *AR.*

W. N. Best has patented the arrangement shown in Fig. A for the occasional use of oil or tar as auxiliary fuel in a furnace equipped for coal
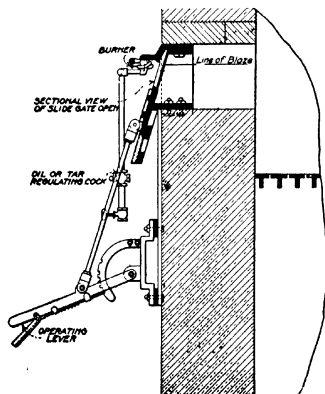
A. OIL BURNER FOR COAL FURNACE
—Power.
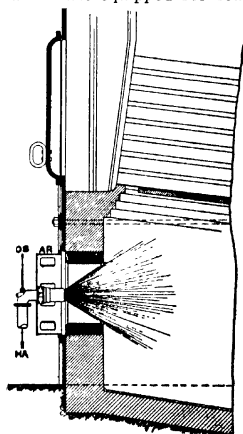
B. COMBINATION OIL AND GAS BURNER

burning. The liquid passes through heating coils to the burner (where it is met by the atomizing steam at right angles, keeping the tip clean) and issues through a diverging groove, giving a flat flame. When liquid fuel is used, the grates can be covered with ashes for protection, and when it is desired to return to coal, the lever is raised, and the slide gate closed, preventing inleakage of air. This can also be used to reduce the air supply when a light load is to be carried with oil.

Kingsley L. Martin describes a coal-fired furnace, Fig. C, adapted for the burning of gas tar. The long sloping baffle makes possible the location of the bridge wall back where it does not turn the flames up against the tubes, and diminishes the heat reflected back to the front wall and burners.
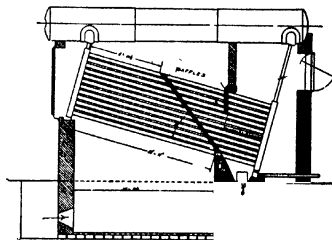
C TAR-BURNING FURNACE
—*Power Plant Engg.*

Burning Pitch.—Quantities of pitch were produced in the manufacture of explosives, consisting almost entirely of carbon, largely in the form of solid unsaturated hydrocarbons, and having heating values of over 15,000 *BTU* per lb. Pitch would make a very good fuel, if it did not soften on the grates and cut off the supply of air at the very time when the latter was most needed to burn the combustible gases. While a number of experiments have been made on atomizing or powdering pitch, a very successful method for burning it solid was that reported by *E. W. L. Nicol.* Some of the fire-bars under a Lancashire boiler were replaced by pitch-bars, with channels for collecting the liquid while distillation was going on, and with steam jets to supply preheated air. The solid matter remaining in the trough was later pushed back and burned as coke. Mixtures of 75% breeze, 18% pitch and 7% coal have also been burned successfully, in ordinary settings.
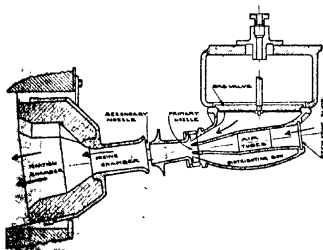
KLING WEIDLEIN
GAS BURNER

BIRKHOLZ-TERBECK
GAS BURNER
—*Amer. Iron & Steel Inst.*
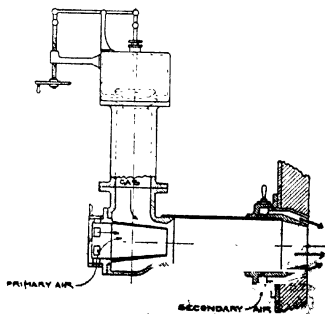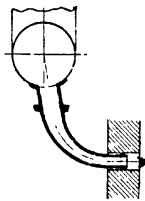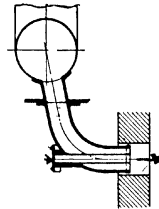
"COMMON" BURNER   BUNSEN TYPE BURNER

BURNING GASEOUS FUELS

Charles J. Bacon gives the accompanying illustrations of typical **burn-ers.** With the common burner shown first, air is not mixed with the gas within the burner, but is admitted through openings surrounding the burner, and through the fire and ash doors. In the "Bunsen" burner the air is admitted through a row of six 4-in. tubes, with adjustable openings, which serve also for observation purposes. The large rectangular exit openings give a low velocity to the escaping gas. In the *Birkholz-Terbeck* and similar burners primary air is admitted and mixed with the gas in the burner, and an additional supply, also under control, is drawn in at the top by the furnace draft. A glass window affords opportunity for inspec-tion of the fire. In the *Kling-Weidlein* burner, also, both primary and secondary air are mixed before ignition. Tests of various burners showed an average boiler efficiency of 60%, although 70 and 75% is guaranteed for some types of burners, and 80% is said to have been reached. Where the air and gas are both subdivided into small streams and intimately intermixed, as with the burner in Fig. F, p. 475, it is possible to secure perfect combustion with no excess air, that is, no CO and no O_2 in the chimney gases. Under these conditions the flame is comparatively short and a large combustion chamber is not required.

The *Standard Bradshaw Burner* has a gradually expanding mixing chamber into which the air is drawn by the energy of the incoming gas, so that, once the air dampers are set, the proportion of air to gas remains constant over a wide range of gas pressures. For the best regulation the pressure in the combustion chamber of the boiler should be kept at or near atmospheric, which can be secured with "balanced draft" apparatus, or approximately by hand manipulation of the stack damper. Tests have shown boiler efficiencies of 81% with balanced-draft control, while 78% has been maintained over long periods on an entire boiler house with hand manipulation of the stack dampers under ordinary operating conditions. The flame is normally held at a point in the flared opening in the boiler setting a few inches from the burner nose, and with decreasing gas veloc-ity moves back toward the nose or even into the mixing chamber, without backfiring, and without requiring adjustment of the air dampers. The average combustion temperature is 2300° F. or higher, increasing the trans-fer of heat to boiler by radiation and reducing the stack temperatures. In the case of boiler plants equipped with the *Bradshaw Pressure Burner,* the boiler house acts as a bleeder, varying its consumption as the gas supply
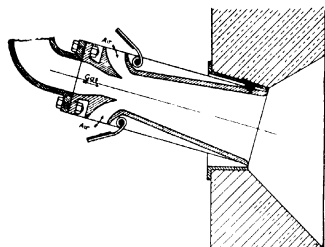
STANDARD BRADSHAW
GAS BURNER
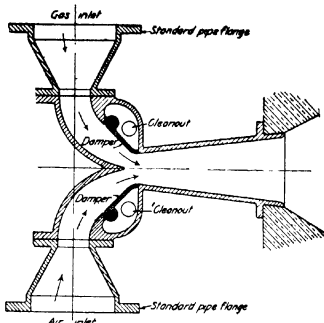
BRADSHAW PRESSURE
GAS BURNER

varies, but maintaining a constant gas pressure in the mains leading to it, so that the gas from the blast furnace reserved for its own stoves can be maintained at a uniform but adequate minimum. The pressure burner at the boiler has a variable throat area, which increases with increased supply, taking the surplus gas at constant pressure, while the air supply, from a constant-pressure fan, is also automatically adjusted in amount, the areas of gas and air throats remaining proportional. The air supply is maintained at say 3 in. pressure, and the gas at 3 or 4 in.

Power Plant Engineering states that it is important in burning gas, as in burning any other fuel, that the combustion chamber be of the right size. Practice varies somewhat, but 0.2 cu. ft. per sq. ft. of heating surface or 2 cu. ft. per boiler HP. is a fair average. The pressure varies with the length of gas passage in the furnace but ordinarily should be kept around two to eight ounces. The velocity of the fuel at the nozzle should be greater than the rate of propagation of the flame, but should not be so great that unconsumed combustibles reach the first pass of the boiler. It should be as near the rate of propagation as possible. If it is too near pulsations in the flow will cause flarebacks. The rate of propagation of the flame in a perfect mixture of combustible and air is about 1000 ft. per sec. As the mixture is not perfect at the burner this velocity will be reduced to about 700 ft. per sec. The total area of the passage for gas and air at the burner should be about 1.6 sq. in. per boiler HP. No one burner should be expected to carry more than about 30 HP.; in other words, the total area of a burner should not exceed about 50 sq. in. or the diameter should not be greater than 8 in. The ratio of the areas of the gas and air nozzles varies with different gases as, in general, every gas requires a different quantity of air for complete combustion. For equal volumes, natural gas requires about 12 times as much air as blast furnace gas, so that the areas of the nozzles will be in this proportion. As the excess air requirements are low, the volume of the flue gases is less than with coal, consequently the passage areas can be lessened by putting in more baffles to give a longer travel, which facilitates absorption.

With care **natural gas** can be burned with an efficiency of over 85%. The main thing is to secure intimate mixture with the air supply, and high temperature, by complete combustion before the gases strike the cooler boiler tubes. A stack height of fifty feet is sufficient to give draft, a high stack tends to draw in excess air. In a plant designed for coal burning, the adoption of horizontal baffling tends to keep the excess air down to the 6% required with gas, and to give better absorption. A large combustion chamber, say 2 cu ft. per rated HP., is also important. *L. A. White* describes an installation where the burners were first placed in the fire doors of a furnace built for coal, but the best results at 200% rating were secured by removing the grates, lining the ash-pit with brick, and placing most of the burners in the ash-pit doors. He recommends a checkerwork wall as affording an incandescent ignition surface for the gas, and also advocates directing the gas against the heating surfaces. The burners should permit easy control and mixture of air and gas, and should not allow backfire. *Marks* recommends the use of small burners, one to every 30 boiler HP., thus preventing blow-pipe action, and it has even been suggested that this number be doubled. With gas passages of 0.8 sq. in. per rated HP., a boiler will produce rated capacity with a gas pressure of 2 in water column. The pressure in the main is usually 6 to 8 in., which allows for throttling and overload. The flame should be blue—a white flame indicates the production of *CO*. The burners must be kept clean, as otherwise the gas supply and the load may be thrown on one section of the boiler. The system of air control illustrated in Fig. A insures an

A. AIR CONTROL FOR GAS BURNER
—Elec. Review.

even supply at varying rates of gas consumption. The pressure drop between boiler room and furnace is maintained constant, and a sheet iron door admitting air is raised or lowered according to the gas pressure between the control valve and the burners.

E. A. Quinn describes the plant of the San Joaquin Light & Power Corp., in which natural gas of 900 to 1080 *BTU* per cu. ft. is used for

B. SETTING FOR NATURAL GAS—
Elec. World

steam generation. The burners are distributed over the floor of the furnace and consist of hollow cylindrical tile, supported by ½-in. pipe nipples and held vertically by shredded asbestos and high-heat-resisting fireclay, with two baffle bricks over each one. All air for combustion enters through the tiles, which are longer-lived than metal burners and can carry from 25 to 200% boiler load

C. TILE GAS BURNER

without vibration or damage to setting. The gas enters the header at $1\frac{1}{2}$ to 2 in. pressure, and is controlled by a gate valve at each boiler, with a lever by which the gas can be reduced immediately if the plant loses its load. Figure B shows a setting for an 800 HP. Connelly boiler, with two shutters controlling the air to the front and back sections of the combustion chamber and an emergency inlet for oil firing should the gas supply fail momentarily. Tests on an 825-HP. M-30 Stirling boiler, with less efficient setting, gave the following results:

Boiler Rating	CO_2 in Flue Gas	Temperature of Flue Gas	Efficiency
(%)	(%)	(° F.)	(%)
84	9.88	443	84
110.6	10.5	518	84.7
139.	9.8	578	82.7
163.64	10.64	514	82.2
171.2	9.3	625	78.3

The gas consists mostly of methane and ethane with traces of illuminants and 1 to 6% CO_2, and as it burns partly to H_2O, the maximum theoretical CO_2 obtainable varies from 8 to 13%. Daily analyses are made, as the composition varies according to the well being tapped.
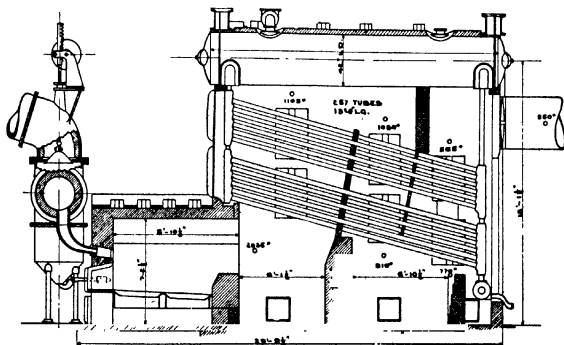
500 H.P. B. & W. BOILER

D. BOILER EQUIPPED WITH COMMON BURNER, FOR UTILIZING BLAST FURNACE GAS

In burning **blast furnace** and **producer gas** it is important to provide sufficiently long flame travel, and ample furnace volume, say 1½ to 2 cu. ft. per rated HP., to secure perfect mixing. Gas directly from blast furnace contains ore, coke and limestone dust, which tend to reduce heat transmission by collecting on boiler tubes. It also contains considerable quantities of moisture, which carries heat away. By washing the gas in a spray tower the dust content can be reduced from 3 to 0 2 grain per cu. ft., and the greater part of the moisture condensed. While this cooling, say from 300° to 80° F., involves a loss of sensible heat, it is generally found profitable. The best results are secured where the air and gas are properly mixed and have ample space for combustion. It is generally necessary for the boiler to use the gas at whatever variable pressures may be available; therefore it is desirable to control the air supply and to make frequent flue gas analyses and pyrometer tests. Boilers equipped with the so-called "common burner," which is simply a rectangular pipe terminating in an opening into the furnace, ordinarily operate at about 50% efficiency, although in the installation illustrated in Fig. D, described by *Ambrose N. Diehl*, 72% efficiency has been reached, due to the comparatively large size of the unit (500 HP.), long combustion chamber, good damper regulation and careful supervision

Grant Bradshaw states that the efficiency of stoves used in connection with blast furnaces varies from 50 to 75%, and that stoves of 58% efficiency would consume 27% of the top gas produced under the following conditions:

Temperature of free air....	60° F.
Cu. ft. air per lb. coke.............'.................	55
Relative humidity	70%
Temperature of air entering stoves...............	225° F.
Blast temperature	1200° F.
Blast pressure	18 lb.
Coke consumed per ton of iron produced..........	2240 lb.
Heat value of coke per lb........................	12900 BTU
% coke in top gas...............................	54.5%
Temperature of top gas to boilers............ ..	375° F.

If the leakage is 6%, 67% of the top gas will remain available for steam generation, and in a plant producing 500 tons iron per 24 hr., boilers of 70% efficiency would generate 4975 Boiler HP. with this gas. For other ratios of coke to iron, the steam production would be:

		Lb Steam Developed From and at 212° per Lb. Coke Charged		Boiler HP. Developed in Plant Making 500 Tons Iron per 24 Hr.	
Lb. Coke per Ton of Iron	% Coke in Top Gas	At 55% Boiler Eff.	At 70% Boiler Eff.	At 55% Boiler Eff.	At 70% Boiler Eff.
1800	50.6	2.68	3.41	2920	3720
2000	52.3	2.78	3.54	3350	4270
2200	54.1	2.86	3.65	3815	4860
2240	54.5	2.89	3.68	3910	4975
2400	55.9	2.96	3.77	4290	5470
2600	57.7	3.06	3.89	4815	6125
2800	59.4	3.15	4.01	5325	6780
3000	61.2	3.24	4.13	5875	7480

Gas pressures vary from ½ in. water column to 50 in. While many plants operate on pressures around 10 in., the average seems to be from 3 to 4 in.

The whole blast furnace system, from blowing engines to gas burners, is a closed system, the pressure starting with 18 to 20 lb. per sq. in. at the engines and dropping to a few inches water column at the burners. The average pressure depends on the burner area, it can be as high as 50 in. without affecting the furnace output or coke rate, although high gas pressure requires high blast pressure and increases the power used by blowing engines. If the gas pressure is maintained too low, there is danger that at time of a "slip" or dropping of stock in the furnace, air will be drawn back into the gas main, producing a serious explosion. By keeping a normal 3 or 4 in. pressure there is also less chance of dropping below the critical velocities at the burners when the gas quantities vary. Below this velocity (which requires a minimum of about 1 in.), no matter how finely divided the air and gas streams are, the mixture will not be intimate and a long flame will result. *Bradshaw* gives the accompanying Fig. E for determining the heat lost in stack gases from a boiler fired with blast furnace gas, simply from the analyses of the gases before and after boiler furnace. The $CO_2 + CO$ is assumed to be 38% in the blast furnace gas as fired. If the gases analyze as follows:

	Blast Furnace Gas	Stack Gas
CO_2	11%	23%
CO	27	0
H_2	3	1.2
N_2	59	75 8
	100	100.0

the intersection of the vertical 23% CO_2 stack-gas line with the 27% CO blast-furnace-gas curve shows that the stack loss is 3.4% per 100° rise in temperature (30% excess air). For stack temperatures of 570° F. and room temperature 70° F., this represents 17% stack loss, and allowing 5% for radiation, which is liberal, the boiler efficiency is, by subtraction, 78%.

Herman C. Siebert reports operating a B. & W. boiler at 270% of rating with a mixing burner, where air was supplied by forced draft, as shown in Fig. F. The gas pressure varied from 2 to 8 in., and the air pressure was throttled down to give a normal pressure of 1 to 1½ in. in the mixing chamber of the burner, the stack draft in the combustion chamber being less than 0.1 in. A maximum efficiency of 68% was obtained by careful manipulation of the air supply, which could also be controlled by governing the speed of the fan by the gas pressure.

In British practice, conical expanding burners have been used, in which, by the variation in gas flow at different points, the ignition assumes a different position according to the gas supply.

When unwashed gas is used, boiler tubes should be blown clean once every twelve hours, preferably by a permanently installed blower.

Care must always be taken not to light a fire in a boiler which may contain an explosive mixture of unignited gas. A small coal fire should be started (or burning waste introduced if the boiler is cold) before turning on the gas.

Gordon Fox and *F. H. Willcox* discuss the use of blast-furnace gas for steam generation. They state that a furnace producing 600 tons of iron per day and using 585 tons of coke per day will produce 58,000 cu. ft. gas per min., containing 94 BTU per cu. ft., of which 27% will be required for stoves and 40,000 cu. ft. per min. will be available for steam-
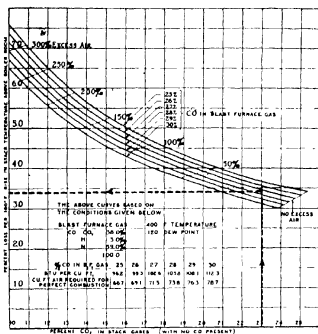
E. STACK LOSS IN BOILERS FIRED WITH BLAST-FURNACE GAS
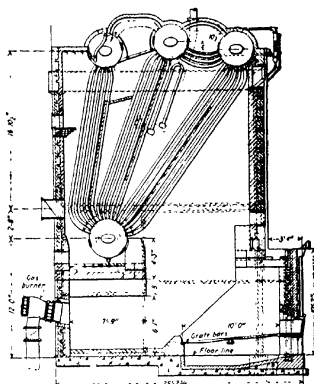
G. COMBINATION GAS AND COAL-FIRED FURNACE—*Power*
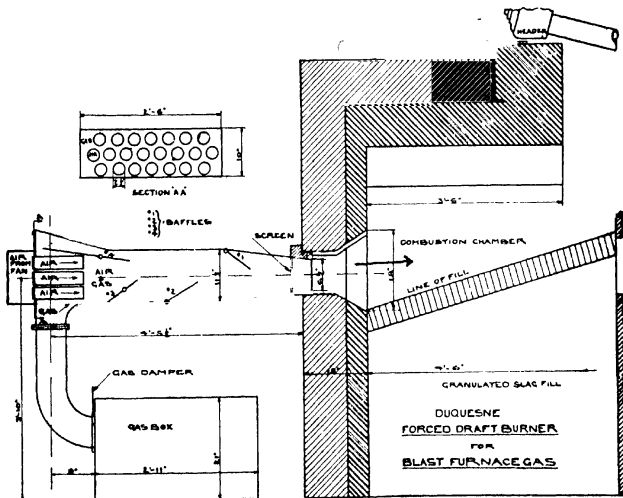
F. BOILER FIRED BY BLAST FURNACE GAS MIXED WITH AIR BY FORCED DRAFT

ing. At 65% boiler efficiency this will furnish 134,000 lb. per hr. of steam at 225 lb. gage and 125° F. superheat. Deducting steam for turbo-blower, pumps and compressor, this will generate, at 16 lb. per kw.-hr., 4300 kw., of which 800 kw. will be required for pumps, ore handling, cranes, pig machine, etc., and the surplus electric power will be 3500 kw. The gas from the producer will contain 23 to 26% CO, 12 5 to 15.5% CO_2, 3% H_2, 58.5% N_2, will escape at a pressure of from 4 to 30 in. of water, at 225° to 550° F., and will contain 2 to 7 grains of coke and ore dust per cu. ft. This can be reduced to 1.75 grains in dry dust catchers or whirlers or to 0.2 grain in wet washers. As the gas is so lean, storage is impracticable, and it must be used as made, and supplemented with other fuel where necessary. Combination gas and hand-fired furnaces can be used, or separate hand-fired furnaces, but hand firing is expensive and inefficient, and if the two classes of boilers are separate, a large investment is required. Supplementary connections for coke-oven gas or fuel oil make a simple and inexpensive arrangement, but if much used the cost of auxiliary fuel may become very high. Where some boilers are fired by gas and some by stokers, efficiency is good, but a large boiler investment is required to allow for spares, and this method applies chiefly where the gas supply averages less than the steam demand. If boilers have both gas and stokers, the stokers can be kept banked and speeded only during casting intervals when the gas fails,—this calls for heavy stoker investment. Combination gas and pulverized-fuel furnaces have advantages, as a large combustion chamber is appropriate for both, and firing rates are quickly adjustable. The cost of mill equipment can be reduced by operating continuously and storing the pulverized coal against times of low gas, and expensive equipment is not required for individual boilers, as with stokers.

With combination gas and stokers, the gas will develop 125% of boiler rating and the stokers 75%, and when the gas is deficient the stokers will take the entire 200% Blast-furnace gas alone will take care of 135% as an average, or up to 200% if necessary on peaks Excess air as low as 10 or 15% can be used, corresponding to 23 or 24% CO_2 in exit gases, and combined boiler efficiencies of 70 to 72% are representative. The volume of combustion gases is 15 to 20% greater than with coal firing, requiring different stack, breeching and baffling. The combustion chamber should be 2.5 to 3 cu. ft. per 10 sq ft. of steam surface, and the furnace temperature is 2200° F. as compared with 2700° F with coal firing. Good mixing in the burner is necessary, with adequate combustion space, as with broad rectangular nozzles a stratified mixture of air and gas sweeps through the furnace, and after-combustion may take place around the tubes, with high stack temperature High draft at the breeching, with rapid gas flow through a number of passes of relatively small area, is desirable. Figure No. G shows one of five 8000-sq. ft. Stirling boilers at Warren, Ohio, equipped for hand firing from in front and with Birkholz-Terbeck gas burners at the rear, in which 70 to 90% of the air for combustion is aspirated by the gas and mixed by whirling. The front walls are reinforced against gas explosions. Room is provided for future stokers, but the present normal operation allows gas to be ·wasted most of the time, the grates being required only when the gas falls off considerably.

N. H. Gellert discusses the advantage of dry-cleaning blast-furnace gas. A 500-ton furnace will produce 59,000 cu. ft. of blast-furnace gas per min. (measured at 62° F. and 29.92 in. mercury) containing 12.5% CO_2, 25.4% CO, 3.5% H_2, 58.6% N_2, and having a gross latent heat of combustion of 92.3 BTU per cu. ft. (5,447,200 BTU per min.), or 5,347,900 BTU per min. low heating value. It will be delivered at 400° F., and if burned in hot-blast heaters or under boilers the flame temperature will be 2375° F., and the combustion products will escape at say 600° F.; the net available heat, considering sensible heat before and after, will be 4,222,917 BTU per min. If the gas is wet-cleaned, the temperature will be reduced to 70° F., and the moisture from 35 grains to 7.98 grains per cu. ft. The flame temperature will be practically unchanged, but the net available BTU per min. will be reduced to 3,964,995, and the 6.5% greater available heat with the hot gas represents, at $6 per ton of coke charged into the furnace, $0.156 per ton of iron made. The total saving in favor of hot cleaning is stated at $0.307 per ton of iron. Electrical cleaning is effected by the use of chains suspended in vertical pipes through which the gas flows. The chains are connected to a mechanical rectifier receiving alternating current at 30,000 to 35,000 volts and converting it to unidirectional current, which causes a corona discharge from the negative electrodes to the pipes. The collected dust is knocked from the pipes every hour or so.

George G. Crawford describes in *The Blast Furnace and Steel Plant* a 5000 HP. installation at the Ensley plant of the Tennessee Coal, Iron & R. R. Co., consisting of six 834 HP. boilers, Fig. H, for 250 lb. pressure and 200° F. superheat, in which blast-furnace gas is the normal fuel and is supplemented by powdered coal when the fluctuating gas supply is insufficient to meet the steam demands. This battery supplements a 24,000 HP. plant in which hand firing on plain grates is used with some of the boilers to take care of gas deficiencies, although this is found to be inefficient and wasteful of labor. Each boiler is equipped with two Bradshaw gas burners *G* in the lower front wall, in which the proportion of air and gas is maintained constant by dampers in the supply pipes, operated by a combustion regulator actuated by the fluctuating pressure in the gas main, the air being available at 6 in. pressure. The pulverized fuel is prepared either from "boiler coal," a middle product from washers preparing coal for by-product coke ovens, with 20 to 25% ash and up to 10% moisture, or high-ash coal screenings, either of which will average between 11,000 and 12,000 BTU per lb. dry coal. It is dried to 1½% moisture in a drier indirectly fired with by-product coke-oven gas and ground in a screen-type pulverizer. Each boiler is equipped with a storage bin of 20 tons capacity, sufficient for 24 hr. at usual rate of operation, or 5 hr. at 200% of boiler rating, and one turn operation of the pulverizer takes care of the usual 24-hr. load. The four Fuller burners *P* enter the top of the combustion chamber through a Detrick flat suspended arch, and the fuel is carried in with about 40% of necessary air, the remainder being admitted through eleven 12-in. circular openings with dampers in the front wall and through inlets on the burners. The combustion chamber is 4754 cu. ft., or 5.7 cu. ft. per rated HP., and the height is 25 ft.

R. T. Haslam and *A. F. Spiehler* give the following formula for **air required** to burn commercial gases. Cu. ft. air *theoretically* required per cu. ft. gas = .00967 BTU — 0.53, where BTU is the higher heating value in BTU per cu. ft. gas. This relationship is exact for hydrogen, CO and
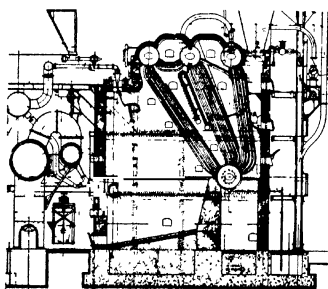
H. SETTING FOR GAS AND POW-
DERED COAL—*Blast Furnace and
Steel Plant*
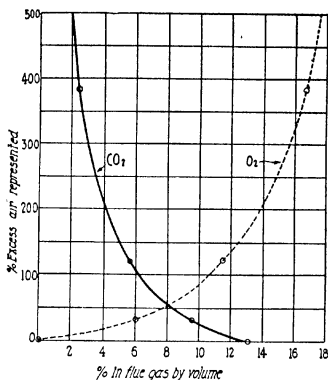
I. INTERPRETATION OF ANALYSIS
FROM COMBUSTION OF A CER-
TAIN GAS—*Davies & Gill.*

saturated hydrocarbons, such as methane, ethane, propane, and nearly so for unsaturated hydrocarbons, such as ethylene, propylene, etc., of which small quantities only are found in natural and artificial combustible gases. It does not hold for acetylene.

The amount of excess air represented by a certain percentage of CO_2 in the flue gases from the combustion of a gas depends on the composition of the gas used, but having once made complete calculations for a given gas, the excess air can thereafter be determined from the CO_2 analysis alone. *J. M. Davies* and *T. T. Gill* present the following, which was calculated by them to cover the combustion of a Pacific Coast natural gas of the analysis given in the second column of Table 1.

TABLE 1

Constituent Gas in Natural-Gas Fuel	Cu Ft. of Constituent per Cu. Ft. of fuel	Volumes of Oxygen Required to Burn 1 Cu Ft. of Constituent	Cu. Ft. of Oxygen Required to Burn Constituent Gas in 1 Cu Ft. of Fuel Fired	Density of Constituent, Lb. per Cu. Ft.	Lb. of Constituent per Cu. Ft. of Fuel Fired	Lb. of Constituent per Lb. of Fuel Fired
CO_2	.0503	...	....	.1163	.00585	.1600
O_2	.0034	...	—.0034	.0846	.00028	.0079
CO	.1264	½	.0632	.0741	.00937	.2567
H_2	.4792	½	.2396	.0053	.00256	.0700
CH_4	.2632	2	.5264	.0432	.01114	.3035
C_6H_4	.0274	3	.0822	.0741	.00203	.0555
C_6H_6	.0129	7½	.0967	.2064	.00267	.0735
N_2	.0372	...	....	.0743	.00276	.0729
	1.0000		1.0047		.03666	1.0000

1.0047 cu. ft. of oxygen required per cu. ft. fuel, divided by 0.2094 cu. ft. oxygen contained in each cu. ft. air, gives 4.8 cu. ft. air required per cu. ft. fuel. The density of the fuel, .03666 lb. per cu. ft., divided by .07658, the density of air at 30 in. mercury and 60° F., gives 0.4775, the specific gravity of the fuel in terms of air. 4.8 divided by 0.4775 gives 10.05 lb. air theoretically required per lb. fuel burned. Table 2 is calculated for the combustible part of the fuel gas, from the given analysis, and gives the total weight of carbon and hydrogen per lb. fuel fired, while the water formed per lb. of fuel equals $(18/2) \times 0.1599 = 1.44$ lb.

TABLE 2

Constituent Gas	Molecular Weight	Lb. of Constituent per Lb. of Fuel Fired	Proportion by Weight of Carbon in Constituent	Proportion by Weight of Hydrogen in Constituent	Lb. of Carbon per Lb. of Fuel Fired	Lb. of Hydrogen per Lb. of Fuel Fired
CO	28	.257	12/28	....	.1100	....
CH_4	16	.303	12/16	4/16	.2285	.0762
C_2H_4	28	.055	24/28	4/28	.0478	.0080
CO_2	44	.160	12/44	....	.0437	....
C_6H_6	78	.073	72/78	6/78	.0674	.0057
H_2	2	.070	...	2/2	....	.0700
Totals ...					.4974	.1599

Table 3 is calculated from three actual analyses of flue gases from an internally-fired bake oven using the given fuel gas, and from the following relationships:

Lb. O_2 in flue gas per lb. fuel $= 32 \, n \times \%$ O_2 in flue gas by volume
Lb. CO_2 in flue gas per lb. fuel $= 44 \, n \times \%$ CO_2 in flue gas by volume
Lb. N_2 in flue gas per lb. fuel $= 28 \, n \times \%$ N_2 in flue gas by volume

$$\text{where } n = \frac{\text{lb carbon per lb. fuel}}{12 \times \% \, CO_2 \text{ in flue gas by volume}}$$

TABLE 3

Sample No.		1	2	3
% by volume in flue gases	CO_2	2.5	5.6	9.5
	O_2	16.7	11.4	5.9
	N_2	80.8	83.0	84.6
n		.01658	.00740	.0043
Weight per lb. of fuel fired	O_2	8.85	2.70	.82
	CO_2	1.82	1.82	1.82
	N_2	37.50	17.22	10.32
	H_2O	1.44	1.44	1.44
Total		49.61	23.18	14.40
Air gas ratio by weight		48.6	22.2	13.4
% excess air		386	122.	34.

The actual air-gas ratio (next to last line) is obtained by subtracting 1 lb. fuel from the line above, and calculating the % excess air from this and the theoretical air-gas ratio of 10.05. Fig. I gives the excess air as a function *either* of the CO_2 or the O_2 in the flue gas, and is correct so long as the fuel gas remains the same and is burnt without the formation of CO. The calculated value of % CO_2 for burning without excess air is found to lie on the curve. (10.05 lb. air per lb. fuel $+ 1$ lb. fuel $- 1.44$ lb. water $- 1.82$ lb. CO_2 formed per lb. fuel $= 7.74$ lb. nitrogen required

per lb. fuel. By the above method, % $N_2 \div$ % CO_2 is found to be 6.68, and as $CO_2 + N_2 = 100$ for no excess air, 13.0% is found to be maximum CO_2 possible for the given fuel.)
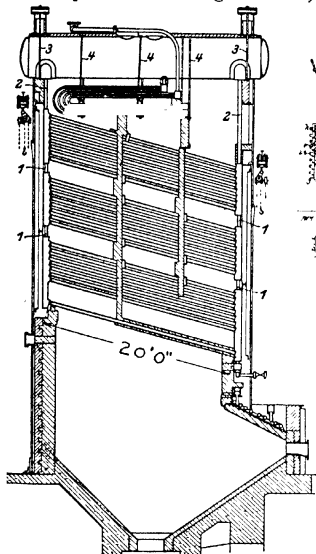
SETTING FOR LEAN BLAST-
FURNACE GAS—Z. d V.
deut. Ingr.
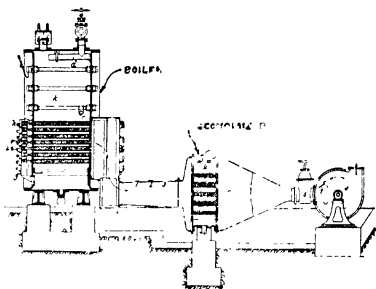
BONECOURT FLAMELESS
GAS-COMBUSTION SYSTEM
—Engg. Mag.

In the Bonecourt **surface combustion** system, coke-oven, blast-furnace or producer gas, mixed with the amount of air required for complete combustion, is burned without flame, directly in the fire tubes of boilers, packed with granular fire brick. The mixture of air and gas is sucked through the combustion tubes, where it burns and keeps the fire brick in an incandescent state, and then passes through an economizer forming a part of the system, which cools the gases to 212° F. or less. Efficiencies of 90%, after deducting the power requirements of the fan, have been obtained, with evaporations of 14 to 21 lb. of water per hr. per sq. ft. of heating surface.

G. R. McDermott discusses the use of the heat in **waste gases** for the generation of steam. By the fourth-power law, the absorption by radiation from gases at 1300° F. would be only 1/10 of that at 2700° F., so that a boiler receiving 65% of its heat by radiation when fired in the regular way would absorb only 7% by radiation when used as a waste-heat boiler, and the convection transfer rate would have to be two or three times as great. According to tests by the *Babcock & Wilcox Co.,* and by *Kreisinger* and *Ray,* and tests on waste-heat boilers, the rate of heat transfer by convection is $R = A + B \; (W/a)$, in which

$R = BTU$ per sq. ft. heating surface per hr. per ° F.
    temperature difference between gas and water
$W =$ gases flowing, lb. per hr.
$a =$ total cross-sectional area of gas passages, sq. ft.

		A	B
Fire-tube, 1-in. *O. D.*		3.5	.0013
" 2-in.		2.0	.0008
" 3-in.		1.5	.00065
" 4-in.		1 1	.0005
Water-tube, 4-in.		2.0	.0014

Although the rate of heat transfer at a given mass velocity (W/a) and tube diameter is greater for a water-tube boiler, the friction loss of the fire-tube boiler is much less. (See also p. 514.) The following comparison of published tests on a water-tube waste-heat boiler with fire-tube boilers calculated to give the same performance with the same draft loss, shows that the heating surface could be cut to less than half:

Type of Boiler	Horizontal Water-Tube	Double-Pass Fire-Tube	Single-Pass Fire-Tube	
Size of tubes, outside dia	4 in.	3 in.	2 in.	1 in.
Number of tubes	.. .	282	525	1,830
Length of tubes, ft.	. ..	28	14	5
Heating surface, sq. ft.	5,030	5,700	3,400	1,960
Weight of waste gas, lb. per hr.	68,000	68,000	68,000	68,000
Mass velocity, lb. per sq. ft. per hr.	2,370	5,900	8,000	8,500
Rate of heat transfer, *BTU*	5 32	5 34	8.4	14 6
Draft loss, in. water	1 45	1.45	1 45	1.45
Initial temp, ° F.	1,330	1,330	1,330	1,330
Stack temp, ° F.	470	470	470	470
Boiler HP.	400	400	400	400

At high mass velocity, the transfer rate varies almost directly as the velocity, so that the total gas-passage area may be decreased without materially affecting the evaporation. 400 boiler HP. obtained from a boiler with 1830 1-in. tubes 5 ft. long, receiving gas at 1330° F. and exhausting it at 470° F, can be equally well obtained by using 915 tubes of the same diameter, increasing the length to 5 25 ft. to provide evaporation to carry the additional fan load due to increased draft loss.

In the usual fire-tube boiler the gas cross-sectional area is too large, and the length of the path too short, but this can be corrected in a long boiler of small diameter, or a multiple-pass boiler, such as the *Bacon waste-heat boiler*. This usually consists of two vertical cylindrical shells, between the heads of which are rolled and electrically welded a large number of small tubes, the gases entering the gas box at the bottom of the first pass, passing upward through the tubes into the transfer flue, from which they are directed downward through the second pass, an economizer being used as a third pass in some cases. For small furnaces, the Bacon boiler is made of a single horizontal shell, the two passes being obtained by suitable baffling in the steel plate gas boxes at the ends of the shell. Boiler scale trouble is minimized, as the feed water is admitted at bottom of the second or "cold" pass where it is gradually heated and rises to the top and passes through an exterior water circulating connection to the bottom of the first or "hot" pass. Gas temperatures are low in the second pass, and the sludge deposited is soft and easily blown off, while the principle of forced water circulation on counter-current principle gives a high rate of heat transfer. As the gases are cooled before leaving to 450° or 500° F., induced-draft fans are necessary, and they aid in the control of the source of waste gas, while the exhaust from the tur-

bines driving them serves to heat the feed. Fire-tube boilers collect little dust, due to sweeping action of the high-velocity gas, and the absence of leaky settings decreases the fan load and the danger of explosions at times of reversal. The tests shown in the following table were made on a *Bacon fire-tube boiler* with two vertical passes, each containing 282 3-in. tubes, 12 or 16 ft. long, receiving gas from open-hearth furnaces. The tops of the two passes are set at the same height and each has a 16-in. nozzle 12 in. from the top flue sheet and connected to a 4 x 7-ft. steam· drum. The bottom of the steam drum, about 30 in. below the top of the passes, is connected to each of the two passes near the bottom by a 12-in. water leg, which receives feed water and delivers it to the bottom connection. The superheater consists of two vertical units in the horizontal flue near the first pass of the boiler. The gases are removed by an overhung-wheel single-inlet fan, capacity 80,000 lb. per hr. at 500° F., with static difference of 5.5 in., at 1115 rpm, efficiency 75%, requiring 37 5 H.P., supplied by a standard non-condensing steam turbine, 3985 rpm, rated 37.5 B.HP.

TESTS OF BACON FIRE-TUBE WASTE-HEAT BOILER AND SUPERHEATER

	Test No 1	No 2
Steam after superheater, lb. per sq. in...	143.0	142.0
Steam after superheater, ° F....	507.0	472.0
Draft before superheater, in. water..	1.45	1.26
Draft before boiler, in water	1.81	1.70
Draft in transfer flue, in water..	2.65	2.52
Draft before fan, in. water.	3.51	3.28
Draft in fan discharge, in. water..	0.96	0.81
Gas before superheater, ° F...	1451	1373
Gas before boiler, ° F.......	1269	1206
Gas in transfer flue, ° F....	793	723
Gas before fan, ° F....	556	525
Boiler HP.	441	424
Gases through boiler, lb. per hr..	79,800	82,300
% available heat removed from gas.................	78.7	80.7
Transfer rate, *BTU* per sq. ft. per hr. per ° F. mean temp. difference between gas and steam........	5 93	6.31

A 150-HP. *Page water-tube boiler* arranged to receive the waste gases from two forge furnaces, both equipped for stoker or oil firing, showed the following results on 8-hr runs with only one furnace in use at a time, used somewhat intermittently for heating gear wheels or shafting:

Kind of Fuel	Ill. No. 1 Nut	Okla. Fuel Oil
Steam pressure, lb. per sq. in. gage	90	110
Gases in boiler furnace, ° F..	1800	2250
Gases leaving boiler, ° F......................	365	450
Draft in boiler furnace, in. water...............	0.15	0.11
Draft in boiler uptake, in. water..	0.11	.075
Dry coal or oil, lb. per hr....................	561	400
Equivalent evaporation, lb. per hr................	1774	3986
Average Boiler HP. developed...................	51.5	115.5
Equiv. evaporation, lb. per lb. fuel...............	3.15	9.92
% of total fuel fired in steam..................	25	50

Fig. A shows the waste-heat boilers used at the Weirton, England, Steel Plant, which receive waste gases from open-hearth furnaces at

1300° F, making three passes through the boiler and two through the economizer. *W. E Groume-Grjimailo* claims that in the *ascending* passes the hot gases tend to form local currents, so that the tubes are not in contact with gases at a uniform temperature, and that the four 180° turns considerably increase the draft loss through the boiler. He suggests a single-pass boiler (Fig B), in which the hot gases are directed to the top in a clear space where they do not come in contact with the ·tubes, so that they tend to form a zone of uniform heating conditions automatically maintained by the influx of hot gases as fast as the gases are cooled and flow downward. Counter-current circulation of gases and water is maintained without baffles, and at any level the various gas streams have the same temperature and weight. No additional chimney capacity is required for the boilers. He also states that if larger regenerators were used, the gases from the furnace would be reduced to 750° F., and that such an arrangement is preferable to the use of the waste-heat boiler.
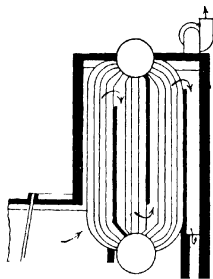
A 5-PASS WASTE HEAT BOILER AND ECONOMIZER
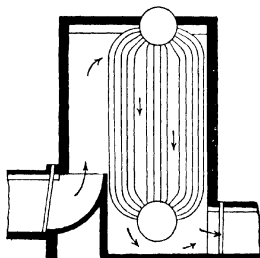
B SINGLE PASS BOILER—*Iron Age*

T. B. *McKenzie* describes installations in British steel plants in which waste gases from open-hearth furnaces are utilized for generating steam, Fig. C. In connection with furnaces of a nominal capacity of 60 to 100 tons, B. & W. boilers with 2193 sq. ft. of heating surface were used, with Green economizers of 1200 sq. ft.

C WASTE HEAT BOILER
—*London Engg.*

heating surface. The waste gases, at 800 to 1000° F., were drawn through the boiler and economizer by a 50-in. multivane fan, and discharged either to atmosphere or back to the furnace chimney. In the former plan the disk-plate dampers on the furnace chimneys are kept slightly open for safety, although this involves some loss of heat. The passages were made short

water-sealed drum valves. The combined heat efficiency of boiler and economizer ranged from 33 to 50%, with a power consumption of the fan corresponding to 10 to 20% of the steam produced. The average weight of steam produced per ton of ingots was 987.5 lb., and with larger boilers this could be brought up to 1200 lb. per ton of ingot. This represents about 44% of the average rate of steam consumption in British steel works, and by the use of the hotter gases from the re-heating furnaces a total saving of 50% can be effected.

Wm. A. Dunkley describes tests made at Joliet, Ill., on the use of bituminous coal as generator fuel for large water-gas sets with waste-heat boilers. The generators were 11 ft. external diameter, each with nominal capacity for producing 3,500,000 cu. ft. of water gas (illuminating gas) per 24 hr., when using good coke as fuel and a blast pressure under the grates of 42 in. water. Exhaust steam from auxiliaries is passed to a header and used in the sets at a pressure of 7 to 8 lb. during the steaming part of the operating cycle, any deficiency being made up by steam received through a reducing valve from the waste-heat boilers. Each gas set has a vertical down-path fire-tube waste-heat boiler, containing 192 4-in. tubes, through which both blast and make gases can be passed. To burn any blast gases that may have passed the checker chambers unburned, a tertiary air supply is introduced near the top of the superheater which precedes the boiler.

To produce 1000 cu. ft. of finished gas with a heating value of 561 *BTU* per cu. ft., required 37 02 lb. of Illinois or West Virginia coal averaging 12,465 *BTU* per lb. as received, 3.72 gal. of oil, and 50.5 lb. steam. 3.76 lb. tar was recovered per 1000 cu. ft. The operating cycle, maintained automatically, was:

Blow, blast air passed through set, blast gas formed sent to
boilers and thence to atmosphere........................... 1 9 min.
Blow-run, air passed through set and boilers to gas receiver.... .2
Down-steam-run, steam passed downward through set, the make
gas formed passing through boilers to gas receiver.......... 1.1
Up-steam-run 1.55
Air purge, air passed through set to gas receiver................ .17

The use of bituminous coal instead of coke did not show as good capacity and efficiency in the smaller sets. It was found that the omission of the "blow-run" reduced gas production by 20%, but saved 0.5 gal. oil per 1000 cu. ft. of finished gas, and that with this omission, the production capacity was about 40% of the nominal rated capacity with coke. The waste-heat boilers showed an evaporation of about 125 to 150 lb. of steam at 125 lb, per 1000 cu. ft. finished gas when both blast and make gases passed through the boiler, and 83 lb when blast gases only were used. Hard tar had to be turbined periodically from the tubes. 49% of the total heat input in coal, oil and steam was in the heating value of the finished gas and 9.1% in evaporation in the waste-heat boilers and these were later raised to 53.7% and 14%. Channeling through the generator fire can be reduced by attention to the sizing of the coal and by care in spreading the charge. The most successful arrangement of checker-chamber brick was No. 3 arch brick spaced 3½ in. in straight flues in the carburetors and 9-in. straight bricks spaced 6 in. and staggered in the superheater. This permits a larger part of the blown-over fuel to sift through to the checker-chamber bottoms, where it can be readily removed through a quick-opening door. The brickless carburetor with high-pressure oil sprays promises much advantage with bituminous coal as fuel.

Cost comparison between coke and bituminous coal was as follows:

	Cents for 1000 Cu. Ft.	
	Favoring Coke	Favoring Coal
Capital charges (interest, depreciation, taxes, marketing securities)	1.44	
Operating labor and superintendence.	0.80	
Operating supplies, general	Neither	
Gas oil	Neither	
Generator fuel		5.50
Boiler fuel	.	2.05
Credit for blown-over fuel.	.	0.34
Maintenance, labor and materials	1.40	
Difference in favor of coal		4.25

Low-Temperature Distillation of Coal.—Increasing attention is being given to processes of distilling coal, by which various valuable oils and gases are recovered and a residual fuel is obtained which, while less in gross heating value, is more suitable for many combustion processes than is the raw coal. This is particularly true of "low temperature" carbonization, which *Soule* defines as distillation conducted at temperatures below those causing an appreciable decomposition of the primary liquid products of distillation. The result is that the 'coke' retains considerable volatile, and there is more liquid and less gas obtained than with high-temperature distillation. *Bone* recommends a temperature of 1025° to 1115° F., while *Parr* suggests 1375° to 1475° F. *C. H. S. Tupholme* gives the following table showing the products from the "Coalite" low-temperature process, and from the older high-temperature processes:

YIELD FROM ONE TON OF AVERAGE COAL (25 to 30% VOLATILE)

	Low-Temperature Carbonization	High-Temperature Carbonization	
		Gas Works	Coke Ovens
Temperature of carbonization .	1 000° F	About 1,800° F	About 1,800° F
Gas	6 000-6,500 cu ft rich gas 700-750 BTU per cu ft	12 000 cu ft of medium quality (Town's) gas, 550 BTU per cu ft	11,500 cu ft poor quality coke-oven gas, 450 BTU per cu ft
Liquid	20 gal Coalite oil fractionated to, say. 3 gal motor spirit 8-9 gal Diesel or fuel oil, and 8-9 gal lubri-cating oil	10 gal coal tar	8 gal coal tar
		Fractionated to about ½ gal motor spirit, carbolic acid, a large amount of naphthalene, fuel oil, etc	
Sulphate of ammonia (from the ammonia) . ..	15 lb	25 lb	28 lb
Residue in retort ..	14 cwt smokeless fuel Coalite containing about 9 10% volatile matter.	13½ cwt soft coke, containing about 1% volatile matter	14-14½ cwt hard coke containing less than ½% volatile matter

The heat employed to carbonize coal by the "Coalite" process is said to be ⅝ of that for high-temperature carbonization.

The resulting solid fuel is hard, crisp and porous; it has sufficient volatile to ignite readily and burns with high emission of radiant heat but without smoke or odor, as it gives off hydrogen rather than heavy hydrocarbons. It can be used for domestic purposes, or under boilers,

either as made or pulverized, or for complete gasification, or, mixed with high-volatile coal, it is used in high temperature ovens for the production of metallurgical coke. The liquid products are double what they would be with high-temperature distillation, and can be subjected to various types of fractionation; the gas, while reduced in quantity, is somewhat richer in hydrocarbons. The ammonia yield is reduced, as considerable nitrogen remains in the coke.

Alfred Gradenwitz describes the *Meyer-Pintsch apparatus* by which tar recovery and steam generation are combined without loss of heat by cooling of the gases or of the coke. Coal from the bunker *a* flows to a distilling shaft *c,* where heat is absorbed from the fire below and the tar and some of the combustible gases (CO and H_2) pass through the pipe *d* to the extraction chamber *e.* Here the tar is condensed, and the permanent combustible gases, while still comparatively warm, pass through the fan *f* to the burners *g,* where they enter the furnace and are burned over the traveling grate *b* onto which the coked fuel, mixed with the remainder of the combustible gas, flows and is consumed. 30-hr. tests at Lichtenberg, under a 5400 sq. ft. Steinmuller inclined water-tube boiler, showed a steaming efficiency of 76.8% without the use of the tar plant and 77.5% with it, but with the latter 2.25% of the weight of the coal was recovered in dry tar, representing 4.3% of the heat in the fuel or an overall efficiency of 81 8%. Taking off larger quantities of distillation gas, the tar was brought up to 5.53%, corresponding to approximately 86% overall efficiency.
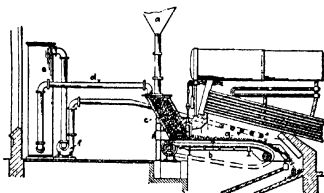
Friedrich Bergius discusses methods of coal liquefaction, in which the object is to return a maximum of the coal content in the form of oil. In the process used by several German companies, pulverized coal is mixed with oil from the process, and the "paste" so formed is exposed to heat and to a pressure of 2200 lb. per sq. in., in the presence of hydrogen gas and of iron oxide. The product is passed through cooling coils, and the gaseous hydrocarbons collected, while the pasty material is further refined and separated centrifugally into automotive fuel, Diesel oil, lubricating oil, fuel oil, impregnating oil, etc., while even the residue yields, when coked, oil and gas in addition to the solid coke, which can be used for fuel in the process, although it contains the original ash of the coal. The hydrogen supply need only be 80% pure, and in practice is advantageously obtained by treating the gas from the process with steam at high temperature. The process is shown graphically in Fig. A. With 100 lb. of raw coal there is fed to the pressure apparatus, 5 lb. iron oxide, 40 lb. paste-oil which has been through the apparatus, and 5 lb. of hydrogen. The product is 0.5 lb. ammonia, 7 lb. water, 20 lb. of light oil, 10 lb. medium oil, 51 lb. heavy oil and residue, 40 lb. paste oil to be recirculated "as is," and 20 lb. gas. Two pounds of the gas is converted into benzine, and the remainder divided between the heating demands of the apparatus and the manufacture of hydrogen for use in it. Of the heavy oil and residue, about 7% is convertible into gas and 23% into oils.

COMBINED FURNACE AND DISTILLA-
TION PLANT—*Power*
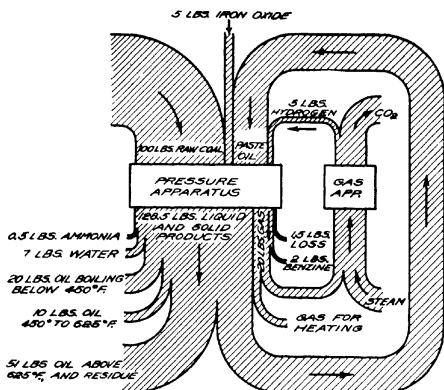
A LIQUEFACTION OF COAL.—Z d Ver. deut. Ingr

REFRACTORIES AND FIRE BRICK

Fire brick are manufactured from natural fire clays composed principally of alumina and silica and classified as plastic or soft, and flint or hard clay. Flint clay has little binding power within itself. The best binder is the plastic clay. Bricks for different purposes are mixtures of different percentages of different clays The physical characteristics of a fire brick apparently determine its qualities so far as boiler furnace work is concerned and its chemical characteristics can practically be ignored.

The quality of fire brick ordinarily is judged by the following:

1. **Plasticity**—Until recently, the melting point of brick was considered the most important characteristic in judging suitability of fire brick for boiler settings. Experience has shown that the plasticity under a given load should be the real basis. The tendency to become plastic shows at a temperature much below the melting point. The allowable plastic or softening temperature will naturally be relative, and dependent upon the stress to be endured.

Steam says that it is probable that practically all fire brick on the market, if tested under the stress met with in arch construction, would show this critical plastic temperature below 2400° F. That an arch will stand for long periods under furnace temperatures above 2400° is due entirely to the fact that its temperature as a whole is far below the furnace temperature, and only the 10% or so of its cross section nearest the fire approaches the furnace temperature

The *Bureau of Standards,* giving a test for determining plasticity, says "when subjected to load tests in a manner substantially as described at 2462° F., and under a load of 50 lb. per sq. in., a standard fire brick tested on end should show no serious deformation, and should not be compressed more than 1 in., referred to the standard length of 9 in." Testing the brick on end may be criticised for boiler purposes, because it is a compression

test, and subject to errors from unequal bearing surfaces, causing shear. Another method, recommended by the highest authorities in ceramics, is to test as a beam subjected to its own weight and not on end. It takes into account the tension element, which is important in arch construction.

Steam says that the plastic point under a stress of 100 lb. per sq. in., which is the average maximum arch stress, should be above 2800° F., and must be above 2400° to enable the brick to be used with any degree of satisfaction.

2. **Fusing Point** is important only as indicating a high critical temperature of plasticity.

3. **Expansion,** in connection with hardness, is a measure of the physical movement of brick as affecting a wall and producing cracking. Lineal expansion should not exceed 0 05 in. in a 9-in. brick at 2600° F.

J. W. Mellor points out that brick after being fired does not contract exactly to its original volume; it may be smaller or larger Therefore, if brick has been improperly burned, when it is again heated there will be superimposed on the ordinary thermal expansion a so-called after-expansion or after-contraction. Doubt is therefore cast upon the accuracy of former determinations of expansion for fire bricks His experiments show that the expansion coefficients of fire clay and silica brick decrease with temperature rise. An average coefficient of expansion for fire brick would be 0.000005 per ° C. or 0.0000027 per ° F At this value, 66 bricks each 2½ in. high would expand 1 in when heated to 2200° F. Expansion is one of the chief causes of failure of fire brick arches.

The coarser the grain of the clay used in a brick, the higher is its softening temperature, owing to the lessened contact of the particles The coarseness of the quartz particles also improves the refractory quality, while angular quartz grains make a firmer mixture than spherical Much of the early prejudice against machine-made bricks was due to poor mixing in the pug mills Clays high in silica are more likely to split On the other hand, fine texture brick resists abrasion and chemical action better. The joints are of course the vulnerable points, which emphasizes the importance of the brick being made true and the use of a joining clay which vitrifies quickly and welds the bricks together when first fired.

4. **Compression** is measured as the load necessary to cause crushing at the center of a 4¼-in. face by a steel block 1 in. square A suggested standard is that the brick should show signs of crushing at 7500 lbs. If it withstands a heavier load, it is too hard for the purpose.

5. **Hardness** is the second reason for the failure in fire brick arches. The harder a brick the greater its tendency toward "spalling" The bricks are subjected to gases at widely varying temperatures and hence to unequal expansion and to localized stresses, causing a hard, brittle brick to fail. Furthermore, joints are rarely perfect, causing overloading at the points of contact between bricks. Hardness is relative and is rated on an arbitrary scale.

6. **Size of Nodules** is the average size of flint grains when the brick is carefully crushed. Small size is that of anthracite rice, large size is that of anthracite pea.

7. Ratio of Nodules is the percentage of a given volume occupied by flint grains. High, 90 to 100%. Medium, 60 to 90%. Low, 10 to 50%.

The above characteristics are suggested for arch brick. For side-wall purposes the compression and hardness limit may be raised considerably, and the plastic point lowered.

Classes of Fire Brick.—*Steam* says that the value of fire brick can only be considered from a relative standpoint. Generally speaking, what are known as first-grade fire brick may be divided into three classes, as follows

Class A. For stoker-fired furnaces where high overloads or other extreme conditions of service may occur.

Class B. For ordinary stoker settings where no excessive overloads will occur, or for hand-fired furnaces with high rates of driving.

Class C. For ordinary hand-fired settings which will be overloaded at rare intervals and for short periods only.

The table below gives the characteristics of these three classes. The hardness of the brick in general increases with the poorer qualities. Unless the hardness is insufficient to enable the brick to withstand its load, additional hardness is a detriment rather than an advantage.

APPROXIMATE CLASSIFICATION OF FIRE BRICK

Characteristics	Class A	Class B	Class C
Safe fuse point, ° F	3200-3300	2900- 3200	2900- 3000
Compression, lb	6500-7500	7500-11,000	8500-15,000
Hardness, relative	1-2	2-4	4-6
Size of nodules	Medium	Medium to medium large	Medium to large
Ratio of nodules	High	Medium to High	Medium low to medium

A fracture gives an approximate determination of the quality of fire brick. Where it is open, clean, white and flinty, the brick is probably of good quality. If it has the fine uniform texture of bread, the brick is probably poor.

Failures of brick work from chemical disintegration are found only occasionally, and principally in bricks which contain a high percentage of iron oxide.

R. F. *Geller* describes a series of laboratory tests made by the *Bureau of Standards* on 42 representative brands of fireclay brick. The refractories were subjected to the following tests: (1) An endurance test in which brick were held at 1450° C. (2642° F.) for 72 hr., both with and without load; (2) a reheating test in which the change in volume and porosity were determined after the brick had been held at 1400° C. (2552° F.) for five hours; (3) a quenching test; (4) the standard A.S.T.M. load test, and two modifications of this test; and (5) the softening points were determined by the cone method, and brick of each brand were analyzed chemically and several examined petrographically. It was found that a close relation existed between data obtained in the endurance, reheating, quenching, and softening-point tests, and that these depended to a remarkable extent on the chemical composition. The results indicated that a refractory which would successfully withstand 15 quenchings from 850° C.

(1562° F.) in running water had a softening point equivalent to at least that of cone 32; that the linear change in the endurance test would not exceed 2% and when transversely loaded the deflection would not exceed 10⁄32 in.; that the percentage absorption after the reheating test would be 6 to 10%; and also that the refractory should be composed of raw materials containing not more than 4% flux and 20% uncombined quartz. The results also favor the dry-press process for manufacturing brick.

It was found that refractories which appeared of highest quality in the laboratory did not always give the highest service, but this was to be expected since no two brands of refractories were subjected to similar service conditions. A field survey showed, however, that in practically every instance brick fail primarily through erosion, indicating lack of refractoriness and resistance to the fluxing action of molten coal ash. The one exception was a suspended arch in which the refractories failed mainly by spalling. In addition, the data from the survey indicated that where the life was relatively long the brick failed by erosion, while, with a short life, the failure was due to combined erosion and spalling.

Raymond W. Howe states that cold crushing tests for fire brick have little value, a good paving brick being stronger than a fire brick, and that the same is true of porosity and specific-gravity tests and chemical analyses. He recommends fusion tests, high-temperature load tests, and spalling tests.

The spalling test indicates the ability of the material to withstand alternate and sudden heating and cooling. While it can be made by heating and air cooling, the water test is more rapid and accurate. The bricks are dried and weighed, exposed for a time to a furnace heat of 3000° F., and then lowered to a height of 6 in in 1½ gal. of water, and dried and weighed again, and this operation is repeated, a record being made of the progressive loss of weight by spalling
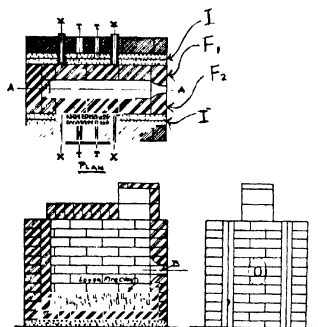
PRACTICAL FIRE BRICK TESTING
FURNACE—*Combustion*

R. C Brierly gives the analysis of good fire brick as 60% SiO_2 and 35 to 40% Al_2O_3, with very little alkali, iron or calcium. For practical testing he suggests building a small test furnace in which one side F_1 is made of the brick to be tested, and the other, F_2, of a brick of known operating qualities. These are enclosed in refractory insulation I, and observation tubes X inserted to the outside of the fire brick, with thermometer tubes T leading to the surface or center of the insulation. Firing is by a small oil atomizer, and the furnace is raised to say 2600° F. (by optical pyrometer) and held there for 24 hours, after which the two walls are compared, and if the condition

is still good, runs are made at higher temperatures with increments of 200° F. A spalling test can be made by cooling the furnace after each run with an air jet of known temperature and pressure.

Fig. A, by the *Bureau of Standards,* shows the observed relation between chemical analyses of fire brick and their fusion points as determined by Seger cones. The results are plotted on the basis of % uncombined quartz and % flux, the latter figure being obtained by subtracting the SiO_2, Al_2O_3 and Fe_2O_3 from 100%.
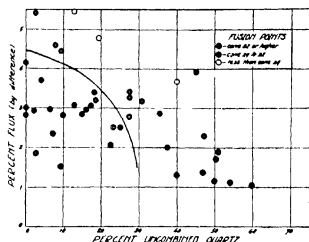
A RELATION OF ANALYSIS AND FUSION POINT IN FIRE BRICK

United States Government **Master Specifications for Fire-Clay Brick,** No. 268, promulgated January 22, 1925, by the *Federal Specifications Board,* recognize the following classifications

Class SH 75 (special high temperature) for severe conditions, as in oil-fired marine boilers at 500% rating, for brick secured by anchor bolts and subject to vibration and rapid temperature changes, and in stationary plants over 175% rating, requiring material with high resistance to slagging, spalling and severe temperatures. The "simulated service test" may be required

Class H 75, for general boiler practice, where resistance to spalling, slagging and high temperature is important.

Class H 57, for use in side walls for general boiler practice, where slagging and temperature resistance is important, but spalling is not Where the whole furnace is to be of the same brick, Class H 75 is recommended.

Class M 73, for moderate temperatures, as in hand-fired boilers under 125% rating, resistance to spalling and slagging important.

Class H 25, silicious brick to resist deformation under load at relatively high temperatures, as with soaking heats with no marked fluctuation of temperature below 1200° F, slagging and spalling not important. H 25 can include bricks of class H 75 which stand the load test.

Class M 7, silicious brick to resist deformation under load, soaking heats at moderate temperatures, no marked fluctuation below 1200° F., spalling and slagging not important.

OUTLINE SPECIFICATION FOR FIRE BRICK

Class	SH 75	H 75	H 57	M 73	H 25	M 7
Silica, %	not over 65				70 or more	70 or more
Softening point, Cone No	31	31	31	29	28	28
	3000° F	3000° F.	3000° F	2930° F	2895° F	2895° F.
Quenchings	15	12	5	2	6	3
Absorption			6—16%			
Deformation					3%	4%

Fire brick shall be of heat-resistant clay or clays burned to produce the desired strength and structure; compact, of homogeneous structure, free from checks, cracks, voids or soft centers, with corners sufficiently solid and strong to prevent excessive crumbling or chipping when handled. Standard 9-in. series brick shall not vary more than ⅛ in. in width and thickness and ³⁄₁₆ in. in length. For special shapes no dimension

shall vary more than 2% from the dimension specified unless greater variation is allowed by contract, but in no case shall a variation of less than ⅛ in. be specified and they shall be free from such swells, warps, twists or distortions as shall prevent ready and accurate laying up with a maximum joint of ⅛ in.

The total silica is determined by the American Society for Testing Materials Standard Method C 18-21, the softening point by their C 24-20, using Orton pyrometric cones, the load deformation test by their C 16-20. The quenching test is conducted on a standard 9-in. straight brick which has been brought to 1400° C. (2552° F.) in not less than 5 hr, held for 5 hr. and cooled. It is then placed with the outer end exposed to air and the inner end flush with inner end of a furnace held at temperature of 850° C. (1562° F.) At hourly intervals the hot end is immersed in running water for 3 min. to a depth of 4 in., allowed to steam for 5 min., and replaced. Failure is noted when the entire plane surface of the heated end has spalled away or can be easily removed by the fingers, each report of the number of quenchings to produce failure being the average of five specimens. The absorption test is made on brick which have been brought to 1400° C in not less than 5 hr. and held for 5 hr. and cooled. Five specimens 100 gm. in weight, from five bricks, are boiled for 2 hr. in water and cooled in the water, and weighed before and after drying to constant weight at 110° C. The average loss in weight is reported as a percentage of the dry weight.

The simulated service test, optional with the purchaser of Class H 75 brick, is made in a small hand-fired oil furnace, 3½ ft. x 1½ ft., page 490, with one side wall of brick and cement of approved brands and the other of brick and cement of the samples under examination, all with 3 in. of insulation. The flame from an air atomizing oil burner sweeps the length of the furnace, curves upward and returns to the front, then up the stack, from which it escapes horizontally toward the rear of the furnace. Two 24-hr. runs are made, at furnace temperatures of 1590° C. (2894° F.) and 1650° C. (3002° F.) respectively, checked by quarter-hourly readings of optical pyrometer sighting on flame through front of furnace above burner. Temperatures of the outer faces of the brickwork are determined half-hourly with optical pyrometers sighting on the brickwork through sillimanite tubes placed flush with the wall, and the comparative insulating properties and final wall conditions determine whether the material tested is acceptable. A spalling test is made by blowing room air on the brick for 2 hr. after shutting off the oil.

Installation: The *Laclede-Christy Clay Products Co.* calls attention to the destructive effects of forced-draft apparatus in old, low-set boiler furnaces, resulting in the liberation of large quantities of heat in a small combustion space, with impinging or scouring action of the flame upon the refractories. Water from boiler washing is also an enemy of brick and arch tile, while if the fire on a stoker grate burns thin, the draft picks up the ash and deposits it on the brick, where it is later melted, and the resulting slag soaks into the brick, reducing its vitality. Brickwork renewals are minimized by placing the first bank of boiler tubes where it can absorb a large portion of the furnace heat by direct radiation. While the ability to withstand high test temperatures is important for brick used for backing brick which is directly exposed to fire, the latter should be selected for physical structure and absence of tendency to react chemically with slag.

B. FIRE BRICK WALL FOR 16 800-SQ FT BOILER—*Power*

Power discusses the difficulty of maintaining the settings under high boilers, due to the temperatures resulting from high driving rates and complete combustion of the volatile gases, and to the compression load from the weight of the upper bricks. In many cases expansion causes the lining brick to bulge into the furnace and break loose, while too liberal insulation on the outside causes the refractories to soften and become penetrated and eroded by ash, and rigid construction permits cracks to develop from expansion and contraction. In connection with the boilers of the Devon station of the *Connecticut Light and Power Co.*, Fig. B, the inside faces of the side and rear walls are made concave so that expansion causes them to approach a plane instead of bulging into the furnace, and the side walls are tilted out at a 5° angle and supported by steel work on the outside. In all four walls radial relieving arches are built *in* the walls to support the upper portions, with an arc of 1¼-in. asbestos expansion joint below each arch. The parts above and below the arches are divided into panels by ¼-in. vertical expansion joints. To prevent soot collecting between the front wall and the mud drum, clips are placed on the nipples

connecting the mud drum with the headers, on which are hung special tiles *T*, which breathe with the boiler and protect the mud drum. Asbestos is packed all around the mud drum, but not in the crack between the tile and the top of the wall. The vertical straight-line wall above the tube line is carried by 20-in. I-beams, also supporting the special tile seal, which is tied by an expansion joint and corbeling to the concave inclined walls of the combustion chamber. This lower wall has no heat-insulating brick, which reduces overheating, and any heat radiated into the boiler room is to some extent recovered by the forced-draft fans.

When the grade of brick best suited to the service of the boiler has been selected, proper **laying** is the important item. It is probable that more setting difficulties arise from the improper workmanship in the laying up of brick than from the raw material. In setting up fire brick linings, a fire clay wash is used on the joints. It is not a binder, but merely a filler. The bricks should touch each other, that is, the fire clay mortar should be as thin as possible.

H. S. Bastian states that he has reduced expansion and contraction troubles in flat-suspended arches by omitting the cement between the part of the tile nearest to the fire, and that these arches are advantageously supported on channels erected immediately outside the furnace walls.

Robert F. Lindsay gives as the first requirement for a commercial refractory mortar that it should be refractory, with a melting point near that of the brick. Fire-clay mortar has this quality if not mixed with too much other matter for eliminating shrinkage and obtaining cold bonding strength. In expansion and contraction and in chemical nature it should resemble the brick. He recommends a dry cement that can be mixed with water on the job; using a thin mixture where dipping is required or thin layers are to be applied; a thick one where troweling is necessary, for thick layers; and a damp mixture for ramming large bodies

Drake Furnace Blocks are used to prevent clinker formation and burning of furnace walls near the bed of the stoker. They have tapered air perforations and lugs on the back forming a space within the 9-in. furnace lining through which air is admitted to the perforations. A cover tile is used over the top course.

APPLICATION OF DRAKE FURNACE BLOCKS

Joseph Harrington states that furnace walls and arches that have failed have been advantageously replaced by a mixture of $\frac{5}{6}$ old furnace linings, with the clinker and glass adhering thereto, and $\frac{1}{6}$ high-grade, high-temperature cement. The old material is ground to a fine size, stopping before the silica modules are pulverized, and the whole is dampened to a stiff mass. The 9-in. furnace lining is removed and the mixture is pounded into place between the standing wall or header row and a

wooden form. Flat-suspended arches are rebuilt with alternate courses of tile and this "ganister," which is found to be lower in conductivity than the tile. Ratings up to 275% have been carried without the deterioration which begins at cracks, and with reduced air leakage. Carborundum bricks are used at the fuel-bed level to resist slice-bar action. He also states that mortar used in setting up new fire brick should have the same chemical characteristics as the brick, as otherwise a flux forms in which particles of ash collect and form slag, the removal of which makes trouble. If the fusing point is much below that of the brick, the mortar melts and leaves cracks so that the gases attack a piece of brick from more than one side. Some cement, sodium silicate and other chemicals must be added to a fire-clay bond to give it strength and plasticity Such material can be spread over partly-worn linings by hand, or applied by an air gun.

D. S. Jacobus states that when furnaces are operated with a slight suction, of say 0 10 in water column, cool air is drawn in through the brickwork, preventing overheating, while with a plus pressure there is a tendency for the gases to leak outward and overheat the setting The plus pressure is otherwise preferable, except with coals where the high temperature fuses the ash and clinker and causes the coal to mat down on the grate, increasing the air resistance through the fuel bed. Fire clay brick of the best quality ordinarily obtainable begins to show plastic deformation under a load of 20 lb per sq. in. at from 2200 to 2400° F., while reduction of the load to 10 lb per sq. in increases the permissible temperature by 200° F. First-class clay brick have a fusion point slightly above 3100° F., but yield through plastic deformation long before they fuse, hence must not be allowed to reach the 2700 to 3000° F. found in the combustion space. With certain fuels, such as blast-furnace gas, wet wood and bagasse, where any temperature attainable can be carried by the brickwork, it is best to absorb but little radiant heat by the boiler tubes, in order to maintain a high furnace temperature and efficiency. In underfeed stoker practice, with the baffle arrangement ordinarily used with B. & W. boilers, the absorption of radiant heat with the boiler operated at its normal rated capacity is over 60% of the total heat absorption. A change in the amount of surface exposed to direct radiant heat of the fire has comparatively little influence on efficiency. While efficiency increases somewhat with temperature, the high temperatures increase brickwork maintenance, hence for a strong fuel it usually pays to expose a considerable proportion of the heating surface to the direct action of radiant heat.

A furnace for operating at high capacities should be larger than for operating at lower capacities; a furnace to give economical results at high ratings therefore involves special problems in caring for the expansion of the brickwork and especial care in the construction of buckstays for holding the brickwork in alignment. The general tendency of large furnace walls which are highly heated is to bulge inward toward the fire, and unless some means are provided to prevent this, they may collapse

The difficulty from slag is essentially a stoker-operating difficulty. Carrying a thick fire may result in but little slagging action, whereas this may cause trouble with the stoker itself through clinker. Thinner fires may remedy the clinker difficulties but result in a greater amount of slag being deposited on the boiler tubes. With certain grades of coal there will be some accumulation of slag on the boiler tubes with most careful stoker operation, and it is advantageous in such cases to provide

access doors for removing the slag. Steam-jet blowers serve to reduce the amount of slag which will collect on the tubes, but are not a complete remedy, so that it is often well to provide access doors.

A. G. Christie discusses the possibility of making better use of **radiant heat** in boiler furnaces. One is ordinarily compelled to sacrifice boiler efficiency by admitting excess air through the fire in order to reduce the furnace temperature to a degree that the fire brick walls will withstand. With powdered coal, air-cooled hollow walls and water screens can be used, raising the furnace temperature, but if the walls could be maintained without the air cooling, more efficient preheating of the air could be obtained by placing an air heater in the flue gases. On account of the high rate of transfer with radiant heat, it should be possible to make the furnace walls of banks of water tubes with brick in the interstices, or of other forms of protected tubes or water legs. It has been claimed that such construction would so chill the fire that high efficiency would not be maintained, but *Christie* states that the combustion of the fuel in the outer envelope of flame will furnish the heat radiated to the adjoining walls without appreciably affecting the interior of the flame, and cites efficiencies obtained of 78% with Scotch marine boilers, 77% with hand-fired coal and 84% with oil in Morrison furnaces, 78% with locomotive boilers—all with enclosed water-cooled fire chambers—and 86% at the Lakeside pulverized-coal plant, equipped with water screens. Even if the temperature is reduced somewhat, the problem becomes how much to sacrifice temperature through highly efficient radiant-heat transfer and still maintain satisfactory transfer by convection in the remainder of the boiler. If the whole of the side walls were water-screened, protecting the walls from overheating even with minimum excess air, the convection boiler surface could be reduced.

Charles Roszak and *Marcel Veron* mention the following methods of increasing the heat received by boilers through direct radiation:

Placing the tubes as close as possible to the grate, other things being equal. (The solid angle varies approximately inversely with the square of the distance, and the energy received per unit follows the same law.)

Placing the tubes parallel to the grate.

Making the ratio of tube surface to grate surface as large as possible.

With high-grade fuel the direct radiation is often reduced too much, due to fear of local flame impingement, which is not justified in connection with a mere increase of the direct heating surface, as the absorption per unit of surface is not any greater, while the gas entering the tube space is cooler, and the load is distributed more equally over the heating surface. The influence of radiation in reducing the actual flame temperature is greatest with an internally-fired boiler $(u = 1)$, less with an external furnace $(u = \text{about } 0.7)$ and practically absent with a "front furnace" $(u = 0)$. The influence of radiation increases when the furnace temperature increases, being a function of the fourth power of the temperature, but when one arranges to utilize such radiation, the temperature naturally falls more and more below the theoretical flame temperature calculated from the initial and final heat capacities. With easily-ignited fuel of high heating value, it is not undesirable to reduce this temperature, increasing the influence of direct radiation by exposing the fire and changing the position of the arch. Changes in the slope of the arch have little effect, as the laws of heat re-radiation are not those of optical reflection (See page 329). While

the attempt to separate the combustion process from heat absorption may improve the former, it is unfavorable to absorption, and overall efficiency in transferring the heat of fuel to steam calls for the optimum solution. The water-cooled walls of the combustion chambers at Hell Gate Station show high efficiency at normal load, although at low load there may be unburnt combustible, and at high loads ignition of gas among the tubes, due to stratification in the furnace. With poor fuel, there may be too much reduction of furnace temperature by direct radiation, as in general such fuels are ignited with difficulty and require reverberatory arches Refractory walls should be used with liquid or gaseous fuels which are sensitive to temperature reduction and where the flame is likely to be extinguished if chilled, or coal fires can be used in connection with gas-fired furnaces.
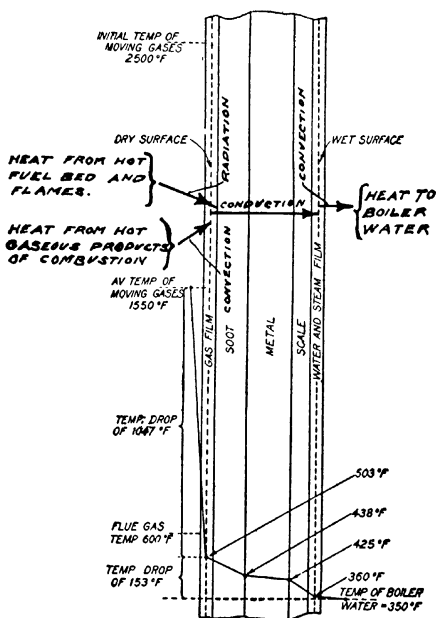
A. WAYS IN WHICH HEAT ENTERS, TRAVELS THROUGH AND LEAVES
A BOILER PLATE

The temperatures shown are those involved in convection and conduction
(See page 502)

Section III—Heat Absorption

HEAT TRANSMISSION

Three modes of propagation are concerned in the transfer of heat from the fire to the water in the boiler, as follows:

Some heat is radiated directly from the incandescent fuel bed to the boiler tubes or plates. This heat does not appear as sensible heat of the gases. The quantity of heat so transmitted would not be lessened, but might be slightly increased, if there were a vacuum between the fuel bed and the metal.

Heat is transferred to the heating surfaces by convection in particles of gas. Cooled particles of gas next to the heat-absorbing surface are continually being replaced by hotter particles, due to movement of the gases.

Heat passes by conduction from the particles of hot gas in contact with the soot coating into the soot and then through the metal and the scale into the particles of water next to the scale.

Fig. A, p. 497, due to the *Bureau of Mines,* shows the temperature relations as heat enters, travels through and leaves the boiler plates.

The dry surface of the heating plate may be defined as the thin layer of gas near or at the outside surface of the soot coating, where the heat ceases to travel by convection and starts to travel by conduction.

The wet surface of the heating plate is similarly defined as the thin layer of steam or water near or at the surface of the layer of scale away from the metal plate, where the heat ceases to travel by conduction and starts to travel by convection, facilitated by the circulation in the boiler.

HEAT TRANSMISSION BY CONDUCTION

The quantity of heat transmitted through a unit area of plate in a unit of time is related to the conductivity and to the difference in temperatures between the dry and wet surfaces of the plate as follows:

$$H = \frac{C}{D} (t_1 - t) \text{ wherein}$$

$H =$ quantity of heat transmitted per sq. ft. of the heating plate in BTU per hr.

$C =$ coefficient of conductivity of 1 in. thickness of the substance between the dry and wet surfaces, in BTU per ° F. temperature difference per sq. ft. per hr.

$D =$ distance between the two surfaces in in.

$t_1 =$ temperature of the dry surface, in ° F.

$t =$ temperature of the wet surface, in ° F.

Different materials have conductivities represented by the following coefficients:

Aluminum	....1394 at 64° F.	Water	......4.16 at 68° F.
Copper	........2666 at 64° F.	Fire brick	...7.0 at 1300° F.
Cast iron	.... 314 at 64° F.	Air	.........0.165 at 32° F.
Wrought iron	.. 418 at 64° F.	Hydrogen	...0.98 at 60° F.
Soft steel	 322	Conductivity of a perfect	
Hard steel	 180	vacuum would be zero.	

The above coefficients of conductivity C are 2904 times the c. g. s. units given in scientific tables.

The conductivity of all substances varies with temperature in a manner not fully appreciated. Although a theory has been proposed which would indicate that the thermal conductivity of solids is constant, it appears that most solids decrease in conductivity with increase in temperature. There are hardly enough data for liquids to say whether the coefficient increases or decreases. In gases, according to the kinetic theory, the coefficient of conductivity is proportional to the specific heat at constant volume times the coefficient of viscosity. This seems to hold well for permanent gases. If it does, the temperature factor in the coefficient of conductivity for air is, according to *Bell*,

$$\frac{C_v T^{3/2}}{T + 185}$$

where C_v is the specific heat at constant volume and T is the absolute temperature in ° F. The change with pressure in a gas is probably negligible, as the coefficient of viscosity is independent of pressure.

Clerk Maxwell offers the following for the coefficient of conductivity for gases.

$K = m C_v \times$ constant,

m is the coefficient of gas viscosity and C_v is specific heat at constant volume.

m is proportional to the 3/4 power of the absolute temperature T, therefore

$K = c C_v T^{3/4}$

The coefficient of conductivity of air at 60° F. is 0.165 BTU per sq. ft. per hr. per ° per in. thick. At 1000° F. the factors, by the two expressions for gas conductivity, give results as follows: Bell 0.331 BTU. Maxwell 0.356 BTU.

Heat flow encounters a resistance through joints in metal bars, or between plates at the point of contact. With this in mind, boiler seams in contact with fires are forbidden.

The conductivity of iron at 400° F., according to the *Smithsonian Physical Tables*, is equivalent to $C = 408$. This means that if two surfaces of a steel plate 1 in. thick are kept at a temperature difference of 1° F., every sq. ft. of the furnace will transmit 408 BTU per hr.

At the usual rating of 10 sq. ft. of heating surface per boiler HP., the heat transmitted per sq. ft. per hr. is

$34.5 \times 970.4 \div 10 = 3350 \ BTU$.

The average boiler tube is 1/10 in. thick, and therefore can pass heat 10 times as easily as the same material 1 in. thick, or 4080 BTU per hr. To

pass the heat through the walls of the tube at the above rate would require only

$$3350 \div 4080 = 0.82° \text{ F. difference of temperature.}$$

The large temperature differences actually existing show that the resistance of the metal can be but a very small part of the total. The soot and scale coatings generally present add to the resistance to heat transfer. Suppose that in a well-kept boiler the resistance to heat transfer of the soot and scale is 10 times that of the metal alone. This would give a total drop of 9.02° F. between the dry and wet surfaces of the tube. Even this is a small difference, and indicates the possibility of working the surface at high rates.

In one test the difference of temperature between the two surfaces of the tube ⅛ in. thick in a Heine boiler was 41.5° F. This means that

$$408 \times 41.5 \div ⅛ = 135,200 \; BTU \text{ per hr. per sq. ft. of area}$$

were transmitted through the tube. This is approximately 4.05 boiler HP. per sq. ft. of heating surface, or 1 boiler HP per 0.247 sq. ft. of heating plate. It should be noted that the temperature of the boiler is close to the temperature of the boiler water, and is affected very little by the hot gases.

TIME, MINUTES
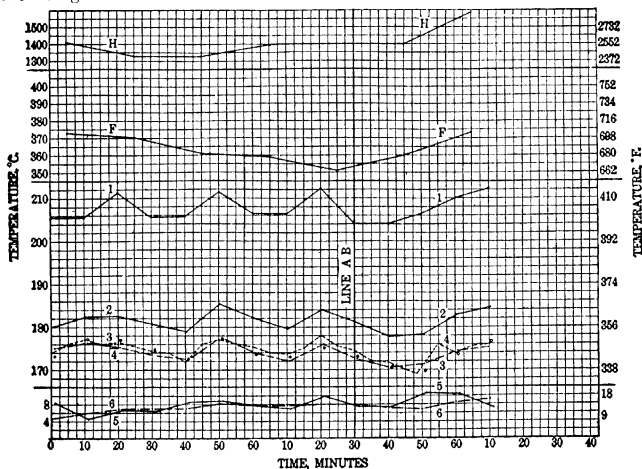
B. TEMPERATURE READINGS IN CONDUCTIVITY TEST

H, temperature of gases entering boiler; F, temperature of gases leaving boiler.
    No. 1, temperature of gas-side surface of a boiler tube in the lowest row at a place where the hot gases enter the boiler.
    No. 2, temperature of the water-side surface of the same tube.
    No. 3, temperature of the steam according to pressure.
    No. 4, temperature of boiler water obtained with copper-tube thermocouple.
    No. 5, difference between temperatures of the water-side surface and boiler water.
    No. 6, excess of water-side surface over temperature of water by thermocouple.
    Average rate of equivalent evaporation, 4.4 lb. per sq. ft. of gas-side surface per hr.
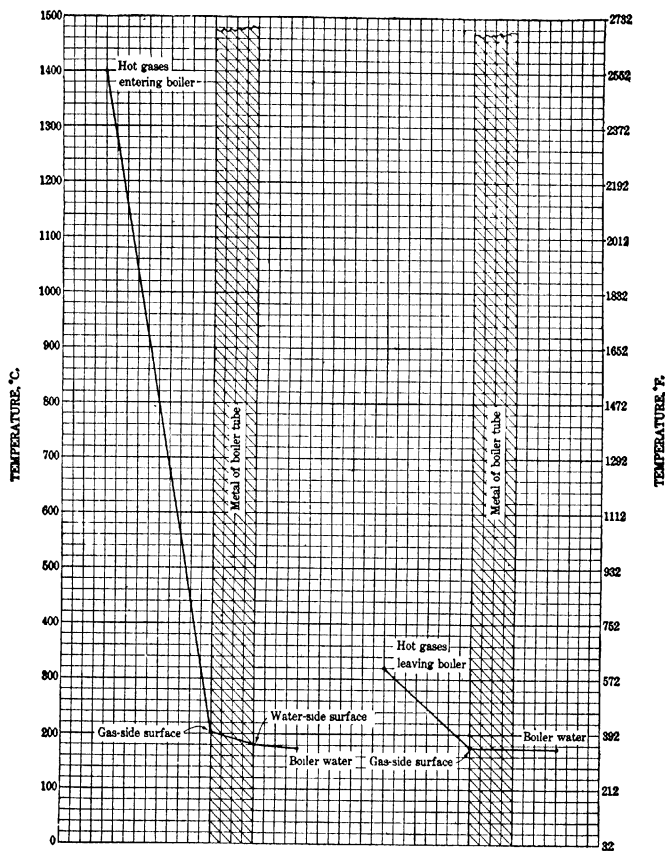
C. TEMPERATURE DROP FROM THE HOT GASES INTO THE BOILER WATER

Diagram on left, temperature drop at place where hot gases enter boiler; temperatures same as given on line *AB*, Fig. B.
Diagram on right, temperature drop at place where gases leave boilers.
In this diagram the horizontal distances have no significance.

HEAT TRANSMISSION BY CONVECTION

The cut in Fig. A shows relatively the average temperature drop between the hot moving gases and the boiler water when the initial temperature of the gases is 2500° F., and the boiler is working at 10 times the usual rate of working a boiler. The drops, from the dry surface to the metal and from the metal to the wet surface, are assumed equal, although it is probable that the drop on the dry side to the metal is higher. These values are estimated, but observation indicates that they are close to the facts.

The principal resistance to heat transmission in a boiler lies between the hot gases and the dry surface. On the inside of the boiler, the water, on account of its great heat capacity, in which is included the relatively great heat of vaporization, readily takes the heat from the surface of the tubes, provided there is sufficient circulation so that the temperature drop at that point is usually small. It is the process of getting the heat through to the dry surface, by radiation and convection, that is slow.

The *Bureau of Mines* made a series of determinations of the temperatures of the furnace gases, of the flue gases, of the water in the tubes and of the inner and outer surfaces of the tubes of a Heine boiler.

The log of the tests is shown in the chart in Fig. B. The chart in Fig. C shows to a uniform scale the temperature drops as the heat travels from the gases to the boiler water, at two different points in the boiler. The startling feature, particularly in the diagram to the left, representing a point where the gases enter the boiler, is the large temperature drop from the hot gas to the gas-side surface of the tubes, and the small drop from this surface to the boiler water. The large temperature difference between gas and metal indicates that this part of the heat path is responsible for the low rate of heat transmission in steam boilers.

Figure D adjoining shows the temperature of the gases at different points in the gas passage. This curve is affected by the cross section of the gas-passages of a water tube boiler, and by the size of the tubes in a fire-tube boiler. The shape of the curve representing the temperature of the gas-side surface is no doubt similar to the curve representing gas temperatures. The temperature of the water is very nearly constant, and therefore is represented by a straight horizontal line. *Kreisinger* says that this curve is from actual measurements, corrected for radiation errors. Measurements made with different sizes of thermocouples were used to obtain the temperatures for a zero diameter thermocouple, which would be correct.

D. PROBABLE TEMPERATURE DROP

In modern boilers by far the greatest part of the heat is imparted to the heating surface by convection. The heat evolved by the combustion of the fuel appears principally as sensible heat of the gases. Regarding convection, *Osborne Reynolds* states: "The heat carried by air or any other fluid from a surface, apart from the effect of radiation, is proportional to the internal diffusion of the fluid at or near the surface, that is, is proportional to the rate at which particles or molecules pass backward or forward from the surface to any given depth within the fluid." This rate of distribution has been shown to depend on:

1. Natural internal diffusion of the fluid when at rest.

2. Eddies caused by motion in mass, which mixes the fluid up and continually brings fresh particles into contact with the surface.

J. E. Bell writes the formula originally due to *Osborne Reynolds* as follows:

$$H = (a + bw) \ (T - t)$$

   wherein $H =$ heat units transferred by conduction and convection
      per unit of tube surface per unit of time,
   $T =$ mean temperature of the fluid,
   $t =$ temperature of the tube wall,
   $a =$ constant, probably proportional to conductivity,
   $b =$ a constant, proportional to the specific heat, and also varying
      with the temperature in some way that so far seems obscure,
   $w =$ mass flow per unit area of the channel.

The quantity a expresses the effect of the natural diffusion of the gas. The quantity b expresses the effect of motion. It includes density and velocity. If the velocity is high, bw becomes large in comparison with a, which then may be neglected.

The quantity $(a + bw)$, to be multiplied by the temperature difference, is usually called the transfer rate, and is distinguished by R. For gases, it varies from 2 to 12 BTU per sq. ft of surface per hr., per ° F. of temperature difference, and for water from 400 to 3000 BTU, depending on the mass flow.

Kreisinger shows curves of the variation of velocity of air in an 8-in. pipe, and the variation of temperature across the pipe. There is a marked resemblance. The largest temperature drop is within a short distance of the surface of the pipe. He believes there is little doubt that the drop in velocity is the cause of the drop in temperature, that is, as the velocity decreases near the wall of the pipe, the transfer of heat by convection is reduced, and the heat has to be transferred by conduction, which in gases is a slow process, and therefore a high temperature gradient is required.

See section on heat transfer from a fluid in a channel to the wall, page 514; also page 481).

HEAT TRANSMISSION BY RADIATION

Stefan stated empirically, and *Boltzmann* later deduced from the theory of electro-magnetic radiation, that the loss of energy from a body emitting full radiation, that is, a so-called black body, is proportional to the bounding surface and to the fourth power of the absolute temperature.

Expressed in BTU per hr. per sq. ft. of surface, the radiation from such a body at a temperature of T ° F. absolute is very nearly

$$1600 \ (T/1000)^4$$

Very hot bodies, regardless of their physical characteristics, seem to emit heat at nearly the above rate. At lower temperatures, the physical surface characteristics have an influence, but incandescent carbon is almost a perfect "black body." The net transfer of heat in BTU per hr. per sq. ft. between two parallel planes is

$$H = 1600 \ [(T/1000)^4 - (t/1000)^4]$$

$T =$ temperature of hotter body in absolute ° F,

$t =$ temperature of colder body in absolute ° F.

In very few cases is the exchange between surfaces as simple as between two parallel "black body" planes. In most cases, in addition to hot surfaces, cooler surfaces are present to absorb radiant heat. These surfaces in turn radiate at rates dependent on their temperatures. The net effect is measured by the difference between the amount emitted by the hot body, and that returned by the cooler. Boiler tubes receive heat by radiation from the very hot fuel bed, from the brick wall, and from the flame. *Bell* says, "Under these circumstances it is not possible to make any accurate calculation as to how much heat can be exchanged by radiation, even though it is assumed that Stefan's law applies Nevertheless, if it is conceived that the radiation is from a black surface at the temperature a pyrometer would show in the flame, the radiant heat absorbed is, I believe, not far different from that given by Stefan's law."

As stated above, the approximate constant 1600 in Stefan's law applies to black bodies. The following values for different substances are derived from *Marks' Handbook:*

Black body 1618	Water 1120
Cast iron, rough, oxidized.. ..1570	Wrought iron, highly polished. 467
Lamp black 1540	Brass, dull 362
Wrought iron, dull, oxidized. 1540	Copper, slightly polished...... 278
Lime plaster, rough white.....1510	

The locomotive furnace presents a simple practical problem in radiation. The hot surface is the fuel bed, and the cold surface is the combined surface of the tube sheet, the crown sheet, the front sheet and the plates on both sides of the fuel bed. The only other exposed part of the furnace is the fire door, which subtends a very small angle of the fuel bed vision, and can be neglected. The heat received by the boiler by radiation then depends upon the area of the fuel bed, and not upon the form of the boiler heating surface.

In furnaces of externally fired boilers, any problem of heat radiation is a more complicated one. On the assumption that the temperature of the furnace lining is the same as that of the fuel bed, the fuel bed and the furnace walls may be designated as the hot surface, therefore any portion of the hot surface will be exposed not only to the cold surface of the boiler,
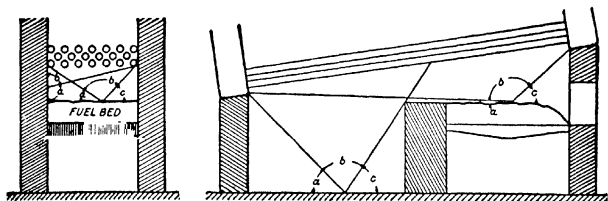
E. APPLICATION OF STEFAN AND BOLTZMANN'S RADIATION LAW TO
AN EXTERNALLY FIRED BOILER

but also to other parts of the hot surface itself Referring to the sketch,
Fig. E, it can be seen that any portion of the hot surface is exposed to the
boiler at a solid angle b, and to other parts of the hot surface itself
through the angles a and c The coefficient in the equation should be multi-
plied by the solid angle b of exposure, expressed as a fraction of a spheri-
cal angle of 180°, to obtain the net heat radiated by each portion of the
hot surface to the boiler In any given case of this type, it would not be
difficult to get the approximate average angle of exposure of the fuel bed
and the walls by averaging the angles of exposure of four or five small
distributed portions of the hot surface.

From the equation, it is apparent that the quantity of heat a boiler
receives by radiation increases very rapidly as the temperature of the fur-
nace rises. Increasing the furnace temperature from 2000° to 3000° F will
nearly quadruple the amount of heat imparted to the boiler by radiation
A drop in temperature from 2500° to 2400° F. will reduce the amount of
heat transferred by radiation by 12%   The effect increases much more
rapidly with higher temperatures

Fig. F shows the relation between furnace temperature and the
quantity of heat imparted to the boiler by radiation, for constant tempera-
tures of the soot coating on the tubes.

Bell experimented to find how much heat is absorbed by a boiler by
radiation. A long tube in a B & W boiler was replaced by a shorter one
of the same size, extending through the front header and just entering the
first baffle. Water was circulated through it, and the quantity and tempera-
ture were measured The heat absorbed corresponded to an evaporation of
75 lb. per sq ft. of surface per hr , more than 10 times the average for the
boiler. The top surface did not receive radiation, and the bottom surface,
besides radiation, also received heat due to the impingement of the furnace
gases. If two-thirds of the surface is considered effective, the evaporation
would correspond to 112 lb per sq ft per hr   Bell believes that more than
100 lb. was from radiation, and 12 lb. from the heat of the first impinge-
ment of the gases. As the gases were at about 2500° F., the evaporation
checked with Stefan's law as accurately as could be expected.

The rate of net heat radiation is per sq. ft. of the totally exposed hot
surface, and not per sq ft of the boiler heating surface. At the same tem-
peratures, the net quantity of heat exchanged between the hot surface and
the boiler surface depends on the extent of the hot surface and the angle

ABSOLUTE TEMPERATURES OF
COOLER SOOTED SURFACES, ° F.
800°
1200°
1500°
1700°
2000°

ABSOLUTE TEMPERATURE OF FUEL BED AND FURNACE, ° F.
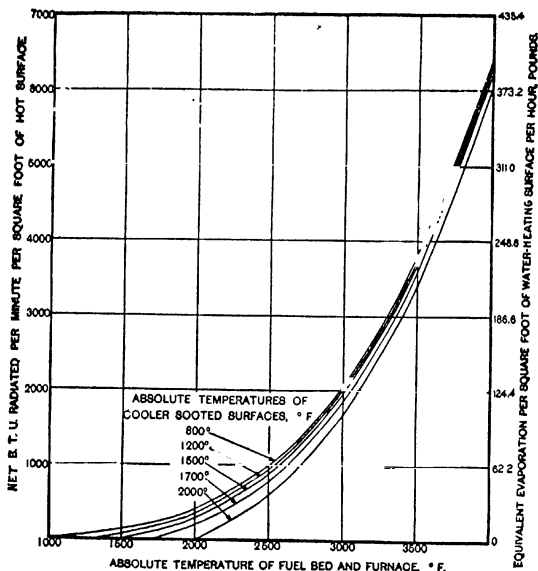
F. RELATION BETWEEN FURNACE TEMPERATURE AND QUANTITY OF
HEAT IMPARTED TO A BOILER BY RADIATION

of exposure of the hot surface to the boiler surface. Neither the distance nor the shape of the boiler surface makes any difference.

In addition to the heat radiation from the fuel bed and the furnace walls, the luminous flame radiates considerable heat. As flames vary in size and shape with different fuels, the rate of combustion and the supply of air, it is difficult to calculate their effects.

It has been sufficiently proven that the temperature of the gases leaving a boiler varies almost directly with the temperature of the gases entering the boiler, both temperatures being reckoned above that of the boiling water. If two boilers have exactly similar construction and baffling, the gases in the one that is so set that it receives more heat by radiation from the furnace will have the lower initial and final gas temperatures, and the efficiency of the boiler will be higher. The gases radiate but little heat to the boiler, but part of the heat generated by the combustion of the fuel is radiated by the hot fuel bed, the flames and the furnace to the boiler, and is never absorbed by the gases therefore the latter enter the boiler at a

lower temperature than they would if they absorbed all the heat generated in the furnace. This means that any heat which the boiler gets directly by radiation is a clear gain. Of course, the presumption is that combustion and air supply are the same in both cases.

The *University of Illinois* ran two series of tests on Heine boilers, the one with the baffle covering the lower row of tubes and the other with the lower row of tubes exposed. The second series gave a considerably lower flue-gas temperature, and an overall efficiency 3 to 5% higher, with but very little smoke. The absorption of heat from the fuel bed and the flames, if carried to an extreme, might result in incomplete combustion and smoke

Summarizing, it can be said that the quantity of heat imparted to a boiler by radiation depends

(*a*) On the extent of the hot surfaces of the furnace and the angle of exposure to the cold surfaces of the boiler.

(*b*) On the difference of the fourth powers of the absolute temperatures of hot and cold surfaces.

In any given steam generating apparatus, the first of the above conditions is fixed, and cannot be used to increase the output of the boiler. It should be noted, however, that where the fire bed is under the boiler much more heat is transmitted by radiation than where the fire is enclosed in a Dutch oven. As to the second, it may be said that in well-operated plants the furnace temperatures cannot be raised much higher without approaching the fusing temperature of the ash and causing deterioration of the furnace lining. It is therefore, advantageous first to transmit a considerable part of the heat directly by radiation, as this permits of a higher CO_2, without unduly raising the furnace temperature.

For the effect of radiation on the measurement of temperatures in boiler practice, see page 192.

B. N Broido discusses radiation in boiler furnaces, particularly in connection with water-cooled furnace walls. He cites a report by *Callendar* and *Julius* that the radiation from six Bunsen flames with a total thickness of 8½ in. was the same as that of a "black body" at 1250° F. (14,000 *BTU* per sq. ft. per hr.) and that the radiation increases with thickness of the flame up to about 24 in, when it becomes 23,000 *BTU* per sq. ft. per hr., which is about 7% of the radiation from a black body at the same temperature, 3300° F. With a clean luminous flame without noticeable particles of fuel, the radiation is about 12% of that from a black body. The radiation from the luminous flames in an ordinary boiler furnace is probably considerably greater than that from a clear luminous gas flame at the same temperature, since the furnace flames are likely to contain a certain amount of coal or soot particles which would make the flame a more effective radiator. Assuming a furnace of cubical shape filled with flame and with a grate at the bottom, the surface of the flame would be just five times that of the grate, which would mean that the radiation from the flame is about 60 to 65% that of the fuel bed, making it an important factor in figuring the heat absorbed in a boiler furnace.

Table 1 shows the temperatures in a furnace near water-cooled walls, at the points indicated in Fig. 1.

Fig. 2 shows how the temperature of the flame varies with the amount of coal burned, also the influence of water-cooled walls upon this temperature. It is based on a furnace 18 ft. long, 18 ft. high, and 24 ft. wide, fired with coal having a calorific value of about 14,000 *BTU* per lb., burned with

1. FURNACE TEMPERATURES NEAR WATER-COOLED WALLS, ° F.

		BOILER RATING (APPROX.) 300%						BOILER RATING (APPROX.) 500%				
		WITH ABOUT 15% CO_2						WITH ABOUT 15% CO_2				
		(Distance couple projects into						(Distance couple projects into				
Location		furnace, in)						furnace, in)				
No.	6	12	18	24	36	48	6	12	18	24	36	48
1	1260	1350	1450	1530	1680	2020	1570	1640	1780	1770	1920	2020
2	1330	1440	1570	1680	1880	1870	1530	1610	1730	1870	2020	2160
3	1500	1600	1690	1780	1940	2050	1750	1810	1880	1990	2150	2290
4	1640	1700	1760	1820	1900	1970	1850	1940	1960	1990	2050	2300
5	1500	1620	1700	1730	1750	1760	1700	1860	1870	1870	1890	1900
6	1460	1600	1670	1740	1900	1970	1690	1790	1820	1870	2050	2150
7	1540	1640	1700	1750	1800	1830	1640	1840	1900	1870	1940	1990
8	1430	1540	1610	1680	1780	1860	1670	1740	1740	1830	1940	2040
9	1580	1660	1730	1770	1830	1890	1780	1900	1930	1950	1970	2130
10	1380	1410	1460	1500	1580	1620	1590	1570	1650	1650	1770	1850

14% CO_2 The first two lower rows of the boiler present about 700 sq. ft. of surface, absorbing heat by radiation, and there is also heat-absorbing surface of about 1000 sq. ft. in the water-cooled walls and bottom. Curve A represents the calculated furnace temperature which would result from combustion with the above coal without any losses. Curve B represents the actual average temperatures in the furnace under the above conditions with different rates of fuel consumption. Curve C shows what the temper-
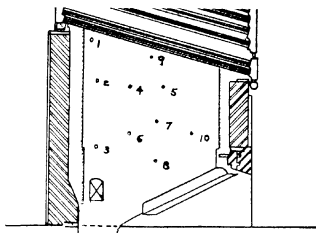
1 LOCATION OF PYROMETERS IN FURNACE WITH WATER-COOLED WALLS
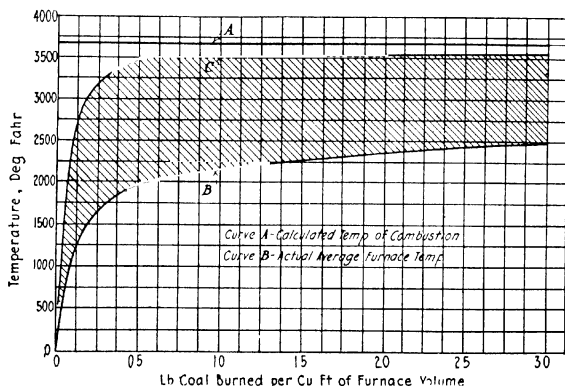
2 ACTUAL AND THEORETICAL FLAME TEMPERATURES—*A.S.M.E.*
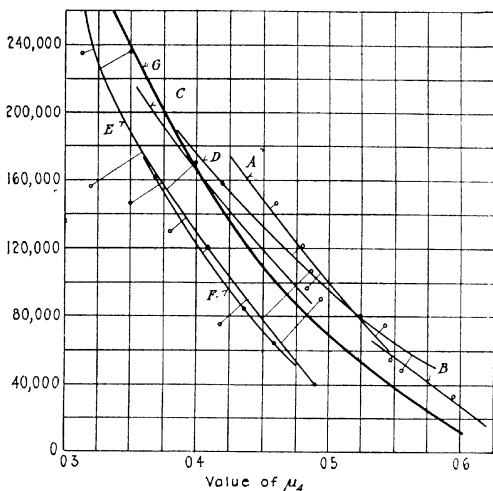
3 FRACTION OF HEAT ABSORBED BY RADIATION

ature would be if no water-cooled radiation surface were present to absorb it. The shaded portion between curves B and C represents the temperature drop in the furnace due to heat absorption by radiation. Curve B approaches curve C as the rate of combustion of fuel increases, which shows that the heat absorbed by radiation does not increase in the same proportion as the fuel burned.

Broido has collected the curves in Fig. 3, in which the abscissas represent the ratio of the heat absorbed by radiation to the total amount generated in the furnace, this quantity being termed "furnace absorption efficiency" by *Wohlenberg*, and designated as U_4 (p. 408). The ordinates represent total BTU liberated per hr. per sq. ft. of surface exposed to direct radiation. Curve A is based on tests in an 1800-HP. pulverized-fuel furnace, with water-cooled walls, at Cahokia, with vertical water tubes in the rear wall, curve B on tests at Sherman Creek on a 600-HP. Springfield pulverized-fuel boiler, provided with two fin-type water-cooled walls at the sides and a radiant-type superheater at the rear wall, curve C on tests made by *Weber* at Vienna on a hand-fired water-tube boiler. Curve D represents the estimated absorption by radiation at Hell Gate station, curve E is based on tests by *W. F. M. Goss* with a locomotive boiler, while curve F shows *Wohlenberg's* conclusions for pulverized-fuel furnaces. The mean curve G varies less than 20% from any of the others, and can be used to calculate probable heat absorption by radiation at various ratings.

By the total heat-absorbing surface mentioned above is meant the projected surface exposed to the furnace, including the surface of the lower
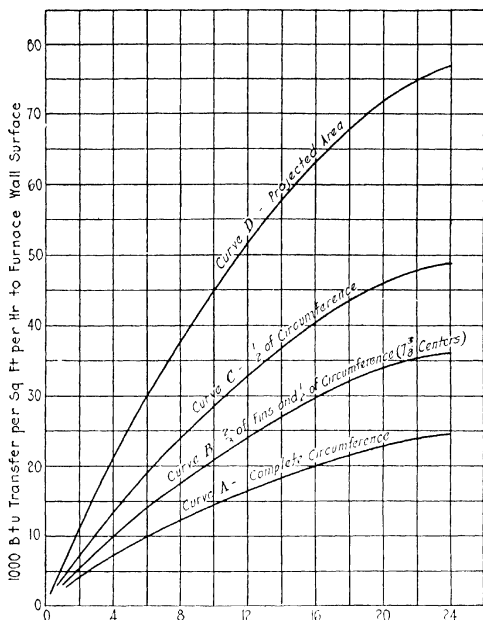
4. COMPARISON OF DIFFERENT METHODS OF FIGURING EVAPORATION OF SIDE WALL SURFACE

Curves based on 800 sq ft of furnace wall surface being water cooled and on boiler having 480 sq ft of projected area exposed to radiation in the furnace Abscissas represent thousands of lb coal burned per hr

—A S M E

rows of tubes of the boiler section, the side walls of the furnace, and its bottom. As the lower rows of boiler tubes, the lower sides of which are exposed to radiation, are always covered by water, they present an excellent heat-absorbing surface It has been suggested, therefore, when figuring the total radiant surface, to add 40% of the lower tube surface. More exact results are also obtained if the projected surface of the bottom screen tube is multiplied by 0 75 to take care of the fact that this surface is mostly covered by ashes which reduce its heat-absorbing capacity.

The heat absorbed by radiation depends on the amount of coal burned, but the heat transfer per *sq. ft* depends on how the surface is calculated. Fig. 4 is based on 800 sq. ft. of water-cooled furnace wall and a boiler with 480 sq. ft. of projected area exposed to radiation. If we assume the whole circumference of the tube to be heating surface, the maximum heat trans-

fer with 24,000 lb. of coal burned per hour is 24,500 *BTU* per sq. ft. If only the projected area is considered as heating surface, the maximum heat transfer for the same conditions is 77,000 *BTU* per sq ft. If half of the circumference is taken, or only the area of the tube which "sees" the furnace, the heat transfer is as shown on curve *C*, while if the projected area is assumed as being the heating surface, curve *D* indicates the heat transfer

He states further that the furnace walls affect only the radiation of **a** relatively thin envelope of the furnace flame and that the interior of the furnace is affected but little by wall conditions. With low-grade fuels the refractory is eroded rapidly by the fused ash, making the use of water-cooled walls desirable. Enough refractory must be in the furnace, how-ever, to reflect sufficient heat so that the temperature of the gases through-out the entire furnace is not lower than that required for combustion. With thorough mixing of air and gases the ill effect of water tubes on ignition could be minimized considerably, and preheated air would also reduce this effect. As the brickwork in stoker-fired furnaces is exposed to pressures above atmospheric, water-cooled walls are of even more value here than with pulverized coals. Brick furnace walls, however, have heat storage capacity which, while it interferes with furnace control, is useful when rapid increase of rating is desired Where coal which has **a** mois-ture content not greater than 4%, a volatile content of approximately 20%, and an ash content of not more than 7 or 8% is burned in pulverized form, there is no reason why the furnace cannot be completely covered with water-cooled surfaces For the same coal burned on stokers, it would be advisable to have the lower part of the furnace lined with brick in order to accelerate combustion on the stoker With coal containing moisture up to 10% and ash of 7 to 10%, about 20 to 25% of the surface will have to be of refractory unless means are provided for effectively mixing the gases in the furnace. It appears, however, that with coal having 25% of moisture or very high ash content, it is not advisable to have more than two sides of the furnace water-cooled; when burned in pulverized form the bottom may also be water-cooled In some cases, it will be necessary also to fill in the spaces between the tubes of the side walls with brick. With preheated air, the amount of cooled surface can be increased in every case.

The water-cooled walls of the stoker-fired furnaces at the Hell Gate station (p. 370) consist of 4-in tubes arranged vertically on each side of the furnace, spaced on about 7-in. centers, each tube having two longitu-dinal steel fins welded onto it diametrically opposite each other, and when placed in the furnace the fins of adjacent tubes butt up against each other or overlap, thus presenting a continuous water-cooled surface to the radiant heat of the furnace. The lower portion of the tubes is covered by fire-clay tile for a short distance above the stoker, which extends along a horizon-tal line the entire length of the furnace. Fig. 5 illustrates an installation of a semi-vertical boiler with water-cooled walls at both sides The water-cooled surface consists of bifurcated tubes which cover the wall com-pletely. Fig 6 indicates another design, in which the walls consist of steel tubes on which are shrunk heavy rectangular cast-iron blocks about 6 in. long and 4 in. wide. These elements are installed on close centers so that the open space between adjacent elements is approximately ⅛ in., while the faces toward the fire form a continuously flat wall. Another design has been suggested consisting of steel tubes imbedded in the wall, with cast-
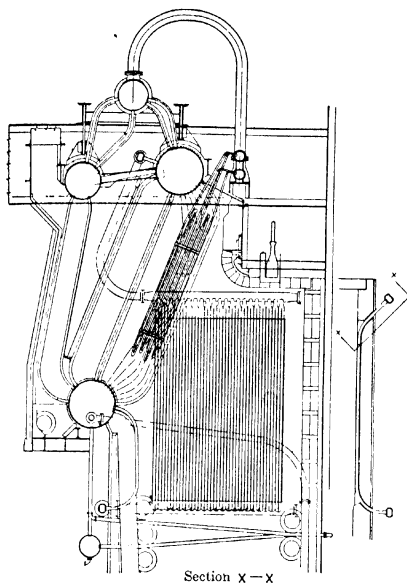
Section x — x

5. SEMI-VERTICAL BOILER WITH WATER-COOLED WALLS OF
BIFURCATED TUBES—*A.S.M E.*

iron blocks fastened to them facing the furnace. These blocks can be
partially covered with refractory material in order to reduce the surface
exposed to direct radiation.

Broido also presents the following study of heat transmission from
gas flowing through a boiler at the rate of 6000 lb. per hr. per sq. ft. of
area, at two points where the gas temperatures are 1400° and 800° F., for
250 lb. steam pressure, or water and tube temperature about 406° F.

Gas temperature, ° F.	1400	800
Total heat transfer rate, BTU per sq. ft. per hr. per ° F. difference, from experiments	7.7	6.65
Calculated total heat transfer, BTU per sq. ft. per hr.	7660	2620
Radiation from the CO_2 in the gas, Shack's equations, BTU per sq. ft. per hr.	1340	280
Radiation from H_2O in the gas	477	107
Total radiation from the gas, BTU per sq. ft. per hr.	1817	387
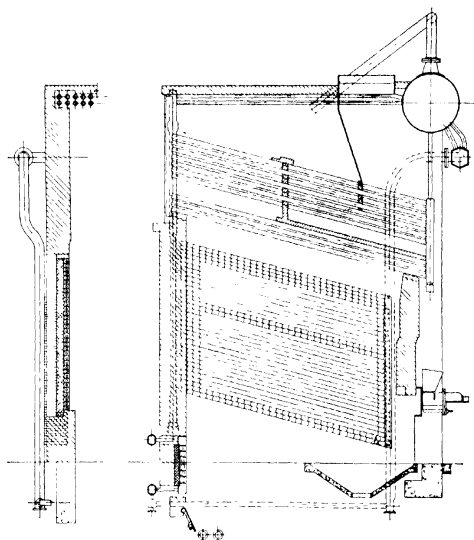
6. WATER-COOLED WALLS OF
STEEL TUBES WITH CAST-
IRON BLOCKS SHRUNK ON
—*A.S.M E*

Heat transferred by convection only, by subtraction,

BTU per sq. ft. per hr............................ 5843   2233
Do., BTU per sq. ft. per hr. per ° F. difference........   5.83   5.66

An increase in velocity of the gases will increase the heat transmission only in the last passes of the boiler, where the radiation is very low and most of the heat is transmitted by convection, so that it is apparently advisable to have the gases pass over this part of the heating surface with the highest possible velocity and in streams of small area. In the passes nearer the furnace, where the gas temperatures are high, it is rather desirable to have them flow with low velocity and in streams of large area in order to increase the radiant effect and, due to the gases being in the pass a longer time, make it possible for them to give off a considerably greater amount of heat.

TOTAL HEAT TRANSFER

Bell gives a formula for the transfer of heat between a fluid in a channel and the wall, obtained by equating the heat absorbed by the tube

walls, using the transfer equation for convection (see page 503), to the
heat lost by the fluid The discussion assumes that the fluid is hotter than
the walls, but if the walls are the hotter, the same equations apply, with
slight changes   The formula assumes a transfer rate or coefficient R,
which is multiplied by the difference between the mean gas temperature and
the mean tube temperature to find the total transfer, and which covers all
the methods of heat transmission:

$$SR(T - t) = Wc(T_1 - T_2)$$

wherein $T_1 =$ temperature of the gas at the hot end of the conduit,

$T_2 =$ temperature of the gas at the cold end,

$$T = \text{mean temperature of gases} = \frac{T_1 + T_2}{2}$$

$t =$ mean temperature of the wall,

$S =$ surface in sq ft

$W =$ weight of flow of gases in lb per hr

$c =$ specific heat of gas,

$R =$ coefficient of heat transmission in BTU per hr per sq. ft per
° F average temperature difference

$(= a + bw)$

The more exact differential equation is

$$(T - t)\ RdS = -Wc\,dT$$

To determine R, the transfer rate, Bell conducted a series of experiments at Bayonne for the B. & W. Co., from which he deduced the following:

$$R = 2\ 1 + 000626\ [1 + 000575\ (T - t) - 0000000865\ (T - t)^2]\ w$$

wherein w is the weight of gas in lb per sq ft. of tube sectional area per
hr and T and t are mean gas and wall temperatures respectively The experiments covered the full range of gas temperatures met with in the
boiler, but did not show the variation with tube temperatures   Bell
believed that this value could be used without serious error for different
tube temperatures and for different tube diameters. The expression is
entirely empirical.

When the gas flow is at right angles to the tubes, as in a horizontal,
cross-baffled boiler, the mean transfer rate is very nearly

$$R = 2 + .0014w$$

wherein w is the total weight of gas in lb per hr divided by the net area in
sq. ft. between the tubes in one row, averaged between the different passes.

The value of $b = 0014$ is greater than the value of the constant in the
expression applicable to a circular flue, which is probably due to the staggering of the tubes It must be remembered that for the same velocities
the friction loss would be more For the same friction loss the value may
be not much different Carrier has suggested that, approximately, in two
structures in which the pressure drop of the gases is the same, the same
rate of heat transmission is obtained   (See also p. 481.)

At very high velocities, the coefficient of heat transfer is almost directly
proportional to the gas flow, and a given area of surface would cool a hot
gas the same number of degrees regardless of the amount of gas swept
over it. At lower velocities, the first term in the expression for the transfer rate is relatively of more importance. In boiler work, around rating,
the gas flow is about 1000 lb. per sq. ft. of net gas passage area per hr.
The transfer rate is 3.4, of which about 2.0 is from the constant term a and

1.4 from the term $bw = .0014\ w$, which varies with the gas flow. It is therefore to be expected that flue-gas temperatures should increase as the capacity increases, and this is true, although it is partly to be explained by the fact that the amount of heat received by the boiler directly from the fuel bed by radiation is a smaller percentage of the whole at higher capacity, resulting in a higher initial temperature of the gases

Regarding the assumption, originally due to *Rankine*, that heat transfer is proportional to the square of the temperature difference, *Kreisinger* says, "Since the rate of heat radiation is proportional to the difference of the fourth powers of the absolute temperatures, and the rate of convection contains the temperature factor as a first power, in the combined rate of heat transfer the temperature factor may appear as the third power or as the square, depending upon whether the radiation or convection predominates The formula where the square of the temperature difference appears can be applicable only in very special cases"

The integration of the differential equation $(T - t)\ RdS = -\ WcdT$ for the case where the wall temperature is constant, as in a boiler, gives the following expression for calculating the surface required for a given cooling effect:

$$S = \frac{Wc}{R} log_e \left(\frac{T_1 - t}{T_2 - t} \right)$$

$S =$ surface in sq. ft,
$W =$ lb of gases per hr.,
$R = BTU$ per sq ft per hr. per ° F average temperature difference,
$c =$ specific heat of gases,
$T_1 =$ temperature of gases at hot end,
$T_2 =$ temperature of gases at cold end,
$t =$ temperature of boiler tube.
$log_e = 2.3\ log_{10}$

Bell says that this equation, together with the expression for the heat transfer rate, and the equation for heat transmission by radiation from the furnace, are all the heat transfer formulæ necessary for the design of boilers as regards heat absorption There is no such thing as a theoretically best length of tube or of gas channel The greater the heating surface and the longer the gas travel, the lower the flue-gas temperature and the higher the efficiency, but this must be balanced against the increased fixed costs and the greater draft requirements Instead of increasing the amount of boiler surface unduly, an economizer or air heater or both can be used, thus gaining the advantage of a greater difference in temperature between the gases and the heated fluid

If, in place of the transfer rate R, its reciprocal is used, an expression is obtained which measures the resistance to heat passage, which is entirely analogous to electrical resistance The total resistance in a boiler or economizer is the sum of three separate and distinct terms, that from the gas to the tube surface, that through the tube itself, and that from the tube to the water. The tube resistance, and the resistance from the tube to the water, are negligible compared with the resistance on the gas side For example, in condensers the conductivity from steam to water may, under conditions of high water velocity and air-free steam, exceed 1000 BTU per hr. per sq. ft. per ° F. temperature difference. This is so much greater than the transmission rates secured in boilers and economizers that it warrants the use of

formulæ for the latter without reference to the velocity of circulation of the water. *Bell* evolved the following formula for the transfer rate from a tube to water contained in it, from *Stanton's* experiments, lowering the first term:

$$R = 50 + 467 \ [1 - 0.133/d]v$$

$v =$ the velocity of the water in ft. per sec, and is used in place of w, the weight, because it is simpler and is not affected by changes in density.

$d =$ diameter of the tube in in.

Jordan summarizes the laws of the variation of **heat transfer as** follows:

(*a*) For a constant mass flow the transfer is proportional to the temperature difference directly.

(*b*) For a given temperature difference the rate of transfer increases with the speed by a linear law.

(*c*) For a given rate of flow and temperature difference the rate of transfer increases with the value of the temperature.

(*d*) The rate of transfer depends on the condition of the surface.

(*e*) The rate of transfer depends on the size of the channel, and the smaller the ratio of area to perimeter, or mean hydraulic depth, the greater the rate of transfer.

E. A. Fessenden offers the hypothesis that during the passage of gas along a tube, the amount of heat lost by a small quantity of gas dQ occupying a length dx of the tube in passing a given point falls off according to the exponential formula for any damping-out process, that is:

loss of heat from $dQ = ce^{-mx}$

where m and c are coefficients which remain constant for any given passage section, rate of gas flow and kind of gas. For use in practical problems, this equation can be reduced to the following form, derived by *Lawford H. Fry*:

(1)	$\log_{10} \ [\log_{10} \ (T_x/T_w)] = \log_{10} \ [\log_{10} \ (T_0/T_w)] - Mx$

where T_x is the mean absolute temperature, ($= °$ F. $+ 460$) of all the gas
      flowing past the point whose distance from the entrance is
      x. It is not the average temperature that would be obtained by
      traversing the passage with a thermometer, because of the
      difference in velocity across the path.

T_0 is the absolute temperature, at entrance to the gas passage.

T_w is absolute temperature of the passage wall. In the case of a
      boiler T_w may be taken as the absolute temperature of the water
      in the boiler without serious error.

x is distance in ft. from entrance to gas passage to the point
      where the gas temperature T_x is to be determined.

M is a coefficient whose value depends upon the rate of gas flow
      and the shape and size of the gas passage, as given in Fig. 1.

Formula 1 can be calculated, if desired, from Fig. 2.

The equation is applicable to cases where the temperature of the wall of the gas passage is practically constant throughout its length, though it may be either above or below the gas temperature. There must be no combustion after the passage is entered. The gas velocity must not be very low, as there is a critical velocity below which the formula breaks down. The flow of gas must be parallel to the walls of the passage, and the cross-sectional area must be constant.
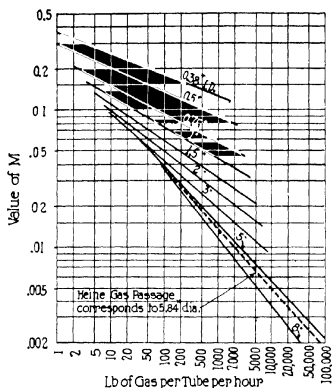
1. VALUES OF COEFFICIENT M.

Value of M (vertical axis) vs. Lb. of Gas per Tube per hour (horizontal axis)

Heine Gas Passage corresponds to 5.84 dia.
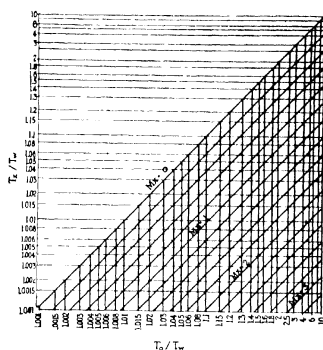
2. CALCULATION FOR EQUATION 1

T_g / T_w

The temperature drop varies directly with M, that is, it falls when a larger flow of gas occurs, or with increased size of flues, which reduces the "hydraulic depth." Low values of M mean lower efficiencies, although the *total* transfer may be increased.

This formula checks with data obtained by the *Babcock & Wilcox Co.*, as plotted in the adjoining Fig. 3, relating to the flow of furnace gases at rates ranging from 94 to 313 lb. per hr., through 2 in. flues cooled by water jackets. It was found to apply equally well to a series of steaming tests made by the *Pennsylvania R. R.* on locomotive boilers with $1\frac{3}{4}$ and 2 in. flues, to experiments by *Fessenden*, in which the water which absorbed the heat was allowed to boil at atmospheric pressure, and by *Jordan*, in which flues of $\frac{1}{2}$ to 2 in. diameter and 3 ft. long, carrying heated air, were exposed to cooling water. By reversing the ratio of

3. RELATION BETWEEN GAS AND FLUE WALL TEMPERATURES
—*A.S.M.E.*

gas temperature to wall temperature the formula can be used for moving gases receiving heat from a flue, as in tests by *Josse* on air at various pressures flowing through a flue 0.9 in. in diameter and 4 ft. long, and by *Nusselt* on air, CO_2 and lighting gas in 0 868 in. pipes 1 to 3 ft. long.

The following tables, based on the formula, show the final temperatures which would be reached by flue gas entering at 2000° F. and flowing through 5 ft. of tube at a temperature of 380° F. (as in a boiler at 180 lb. gage), also the heat transferred in *BTU* per lb. of gas.

Lb. gas per tube per hr.	100	200	400	800	1600
Diam..in.		Final gas temperature ° F.			
½	600	650	705	760	825
1	870	960	1040	1125	1210
2	1080	1190	1300	1390	1475
4	1205	1340	1455	1560	1655
8	1240	1390	1545	1660	1745
		BTU transferred per lb of gas			
½	452	438	422	406	387
1	374	348	324	296	270
2	310	276	240	210	184
4	272	228	170	154	120
8	250	210	160	120	85

Fessenden gives for the *mean* specific heat between absolute zero and T, the absolute temperature in ° F., of flue gas containing 11% CO_2 and 8% O_2,

$$[0.22975 + 0.000016217T - 0.000000000669T^2]\ BTU\ \text{per lb. per ° F.}$$

From the temperature at any point, as determined by the formula No. 1, and this value of the specific heat, it is possible to calculate the efficiency of the gas passage as a heat transmitter, which is defined as

$$(h_o - h_x)/(h_o - h_w)$$

where the $h's$ are heat content of the gas, in BTU per lb., at the temperatures indicated by the various subscripts. Fig 4 shows the "tube efficiency" calculated for various lengths of 4-in. internal-diameter standard boiler tube, gas passing *through* the tube, based on entrance at 3000° F. abs. (2540° F.) and tube-wall temperature 826° F. abs. (366° F.). (The quantities, $W/p = 2$, 4, 8, 10, 16, 32, 64, 100 and 128, refer to lb. gas per hr. per tube, divided by perimeter in in.) $W/p = 10$ corresponds approximately to the normal rate of gas flow in a horizontal return tubular boiler. For this the gas temperature at end of 1 ft would be 2694, 5 ft 1901, 10 ft. 1416, 20 ft. 1034, all in ° F. abs. Decreasing the wall temperature by 150° F. increases tube efficiency about 3%, while reduction of entrance temperature by 500°, leaving wall temperature 826° F. abs., reduces the tube efficiency by about 2%. Fig. 5 gives the efficiencies for the gas passage between the tubes of a Heine boiler, with 3½-in. tubes on 7-in. centers both vertically and horizontally, staggered at 45°. Thus, for a boiler 10 and 11 tubes high arranged 5 tubes wide the net area of gas-passage = 832 sq. in., perimeter of 52 tubes = 572 in., mean hydraulic depth = 832/572 = 1.46 in., corresponding to a diameter of 4x1.46 = 5.84 in in a fire-tube.

The most satisfactory method of utilizing these formulas for the determination of heat interchange is to find the gas temperature at any desired point from the formula (1), and the corresponding change in heat content. The rate of transfer *at a given point*, however, is given by the following.

$$U = -63.6\ \frac{W\,S\,T_x}{p\,(T_x - T_w)}\ M\ \log_{10} \frac{T_x}{T_w}$$

where U is in BTU per sq. ft. per hr. per ° F.

W is in lb. of gas per tube per hr.

p is perimeter in in.

S is the *instantaneous* specific heat of the gas at temperature T_x, other symbols as before.

TUBE LENGTH - FEET
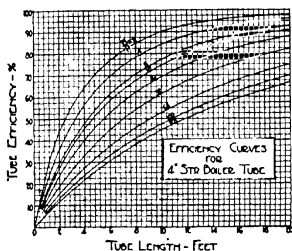
4. TUBE EFFICIENCY, 4-IN TUBE

TUBE LENGTH - FEET
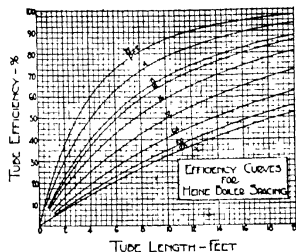
5 TUBE EFFICIENCY, HEINE GAS PASSAGE

$W/p = 2$, 4, 8, 10, 16, 32, 64, 100, 128, smaller values on the upper curves
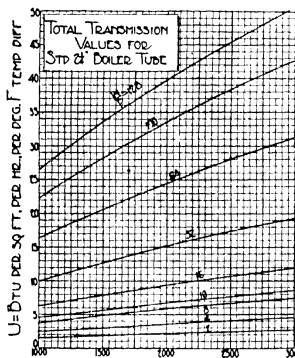
GAS TEMPERATURE-DEG FAHR ABS
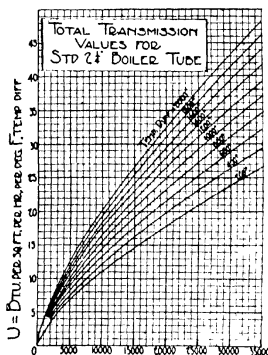
$\frac{A}{A}$=LOG GASES PER SQFT CROSS-SECTION PER HR

6 AND 7 HEAT TRANSFER RATE, 2¼-IN BOILER TUBES

$W/p = 128$, 100, 64, 32, 16, 10, 8, 4, 2, larger values on upper curves

Temp. diff = 2000, 1800, 1600 1400, 1200, 1000, 800, 600, 400, 200
Larger values on upper curves
—*Pa State Col Bull.*

For wall temperature $T_w = 826°$ F. abs, $U = -KM(W/p)$, where K has the following values

T_x	1000	1500	1600	1900	2000	2400	2500	3000
K	7.90	10 04	10.42	11 53	11.91	13.28	13 59	15 17

Fig. 6 gives values of U for 2¼-in. tube at wall temperature $T_w = 826°$ F. abs., for various gas temperatures and quantities flowing, and Fig. 7 the same data as a function of the temperature differences from 2000° down to 200° F.
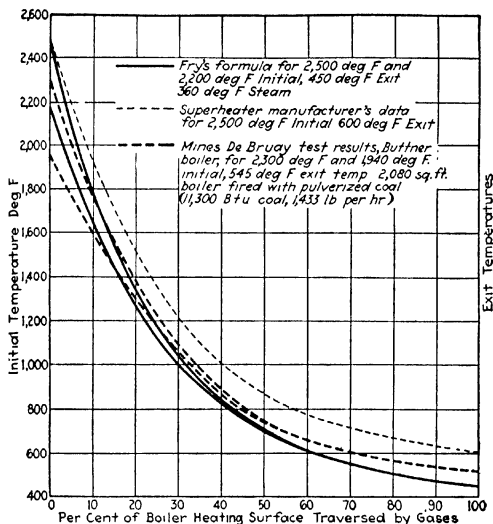
A. TEMPERATURE DROP IN BOILER PASSES—*Power*

J. G. Coutant gives in Fig. A a study of the temperature drop of
gases passing through a boiler. Values from *Fry's* formula and that of a
superheater manufacturer are given, together with results obtained at the
Mines de Bruay, France, burning pulverized fuel at the rate of 1,433 lb.
per hr. (11,300 *BTU* per lb), at 14% CO_2, in a 2080-sq. ft. Buttner boiler
having a superheating surface of 54 sq. ft. As originally installed, the
furnace volume was 880 cu. ft. with 65 sq. ft. of boiler-heating surface
(projected area) directly exposed to the fire. The initial temperature was
2,300° F. and the reduction through the boiler gave an exit temperature
of 545° F. The boiler furnace was then changed and the volume
increased to 1,140 cu. ft. with 95 sq. ft. of surface directly exposed to the
fire. With the same amount of fuel and air being burned as in the first
case, the initial temperature became 1,940° F., and diminished through the
boiler to the same final temperature, 545° F. This would indicate that:
(a) When burning the same amount of fuel and air in a boiler furnace,
the exit temperature of the gases remains the same in each case and is
not affected by the proportion of heating surface directly exposed to the
fire; (b) superheat is not affected if the superheater is placed after 50%
of the boiler surface; (c) an additional amount of the direct boiler-
heating surface does not increase the total heat absorption. By increas-
ing the amount of direct heating surface the heat absorption of the boiler
is more uniformly distributed and the local strains in any particular part
are decreased, removing the objection to the use of pulverized fuel under
old boilers.
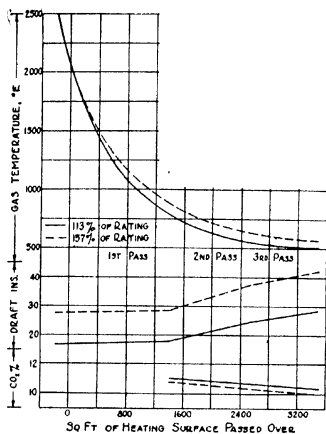
B PERFORMANCE OF STEEL EN-
CASED BOILER AT DIFFERENT
RATINGS
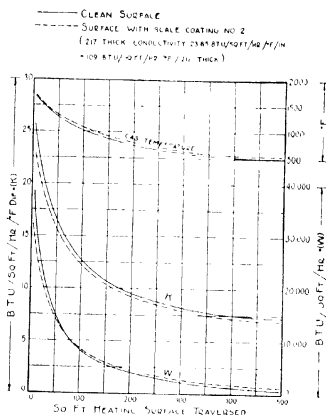
C TEMPERATURE AND HEAT
TRANSMISSION AT DIFFERENT
POINTS IN A BOILER

Fig B, by *Joseph Harrington*, shows the temperature relations in 24-hr. tests at different ratings of a 350-HP boiler with a chain grate, the boiler being encased in ¼-in sheet metal plate, with 2-in magnesia block insulation between it and the brickwork. There was a difference of only 0.85% in CO_2 in the different parts of the setting, showing that air infiltration was reduced to a minimum.

Fig. C, from data by *Reuthnger*, gives the temperature drop of gases and the transmission through heating surfaces exposed to them, at various points in the path of an experimental boiler, under conditions similar to boiler practice, with the gas entering at 1750° F, and the water at 350° F.

Carl Fred Holmboe reports tests on heat transmission from steam to water, superheated steam passing through a tube 078 in thick enclosed in an insulated tube carrying water. Temperature readings were made on both water and steam, and the steam flowing was condensed and measured, the heat transmission rate, figured on the basis of logarithmic mean temperature difference, being plotted in Figure D, for steam at atmospheric pressure and at 54.4 lb gage. The solid curves, representing formulas given by him connecting k with the steam velocity, approximate the observations, while the dotted curve shows *Seer's* formula. This overall transfer rate k is connected with the individual transfer rates at the two fluid surfaces by the following relations:

Logarithmic mean temperature difference = $(D_1 - D_2)/2.3 \log_{10}(D_1/D_2)$, where D_1 is the temperature difference at one end of the apparatus, and D_2 at the other.
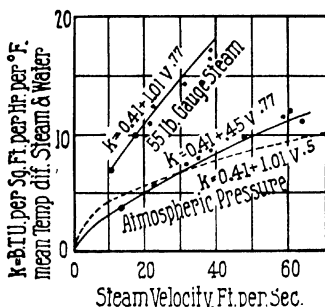
D. HEAT TRANSMISSION, STEAM
    TO WATER--*Holmboe.*
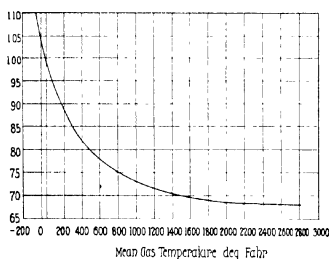
G. CORRECTION FACTOR (p 524)

E   GAS FLOW IN A WATER-TUBE
    BOILER MODEL WITH STAG-
    GERED TUBES

Velocity 3 28 ft. per sec , 0.63-in tubes—
Thoma
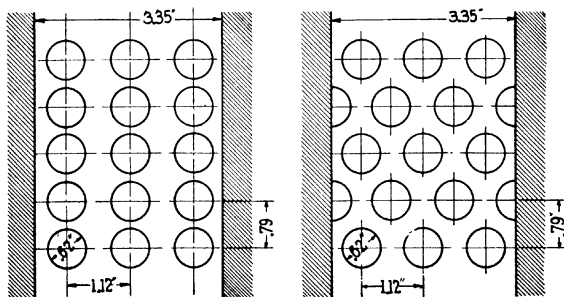
F. BOILER TUBE MODELS, DIMENSIONS IN INCHES
                                              —*Thoma.*

$1/k = 1/k_1 + t/C + 1/k_2$, where

  $k = BTU$ per sq. ft. per hr. per ° F. m t d between steam and water
  $k_1 = BTU$ per sq. ft. per hr per ° F. m t d between steam and metal
  $k_2 = BTU$ per sq ft. per hr per ° F m t d between metal and water
  t = thickness of metal in in
  C = conductivity of metal, BTU per sq ft per hr per ° F. between
    its two surfaces, for 1 in thick

$t/C = .078/2400 = .0000325$, and as the water speed was over 9 ft. per
  sec., k_2 was greater than 1000, and $1/k_2$ less than .001, hence
  k_1 is practically equivalent to k, and k is properly investigated on
  the basis of steam velocity only See page 558 on air heaters.

From consideration of the kinetic theory of gases, *Hans Thoma* has derived the following relationship for heat transfer to or from gas flowing through a nest of tubes:

$$k = 3600 \frac{a}{A} c g \frac{h}{v}$$

where $k = BTU$ per sq. ft. heating surface per hr. per ° F. difference
    between the fluid and the tube wall
  a = cross-sectional area of the effective flow area, excluding that
    taken up by surface layers of gas, sq. ft. ($= d + e + f$ in
    Fig. E) × length of tubes.
  A = total heating surface, sq ft.
  c = specific heat of the gas at constant pressure, BTU per lb. per
    ° F.
  g = acceleration of gravity, 32.2 ft. per sec[2]
  h = pressure drop in the apparatus, lb per sq. ft
  v = actual gas velocity, ft per sec

He states that for practical heat transfer that arrangement is best which combines low gas velocity with high pressure drop, and that the observed high transmissions with increased velocity are really due to increased pressure drops. Fire-tubes are less efficient than water-tubes, because in the long, straight fire-tubes the surface layer gradually attains an appreciable thickness, and the friction finally becomes small for a given velocity. Water-tubes, however, are continuously swept by fresh gas streams, and the constantly-renewed surface layer remains thin, creating comparatively high friction with a given velocity The application of this formula is complicated by entrance and exit and reversal losses, which may form half of the measured pressure drop. Tests by *Fuchs* showed a pressure drop in a boiler of 0 38 in. water when burning 7250 lb. of lignite per hr., the gas velocity being 23 ft per sec. Allowing 0 08 in. for exit loss, 0 08 in. for three reversals of direction, and 0.01 in. for density changes, the net pressure drop is 0 21 in. water, or 1.095 lb. per sq. ft.; $a = 24.6$, A, including superheater, $= 3800$, $c = 0.27$, $h = 1 095$, $v = 23$; calculation gives $k = 9.65$, the value observed by *Fuchs* for the boiler heating surface only was 8.6.

Rietschel describes a test on a *Sturtevant Air Heater*, with four rows of staggered tubes filled with steam, on which the air impinged as flue-gas does on the water-tubes of a boiler. The observed pressure drop was 0.42 in. or 2.20 lb. per sq. ft., specific volume of air at 32° F. = 12 3

cu. ft per lb., air velocity 32.8 ft. per sec. Taking the loss at exit as being half of that to produce velocity, the net pressure drop is

$$2.20 - \frac{1}{2} \left\{ \frac{32\,8^2}{2 \times 32.2 \times 12.3} \right\} = 1.53,$$

$a = 0.256$ sq. ft., $A = 20.1$ sq. ft., c at $32°$ F. $= 0\,24$, $h = 1.53$, $v = 32.8$; with these values, *Thoma's* formula gives $k = 16\,3$, as compared with 16.8 as observed by *Rietschel* The set of calculated and observed values of k were as follows:

Air Velocity, Ft per Sec.	16 4	32 8	65 6
4 rows, calculated..	10.46	16 30	26.45
observed........	11 15	16 80	25.33
2 rows, calculated. .	9 43	14.35	22.14
observed..	9 72	14 62	22.02

From a study of the analogies between heat-transfer phenomena and diffusion of gases, and from experiments on the rate of diffusion of ammonia gas through boiler-tube models of the types illustrated, Figs. E and F, *Thoma* derived the following expression for heat transfer in terms of gas velocity and tube diameter, for air at $32°$ F. flowing past the outside of staggered tubes arranged as in the right-hand part of Fig. F.

$k = BTU$ per sq. ft. tube surface per hr. per $°$ F. difference between tube and gas

$$= 3\,03\ v^{0\,6}/d^{0\,4}$$

where $v =$ gas velocity in ft. per sec.

   $d =$ outside tube diameter in in

For tubes arranged as in the left-hand figure, the coefficient is reduced to 2.54. For other mean gas temperatures, the coefficient should be multiplied by the factors shown in Fig. G.

Tests by *Fuchs* on tubes 2.54 in. in diameter, swept by gases at mean temperature of $752°$ F. flowing at rate of 23 ft. per sec., showed $k = 8\,57$, calculation by above formula gives 8 61.

W. H. McAdams and *T. H. Frost* give the following for heat transfer between a clean pipe wall and water flowing in turbulent motion through it:

$$h = 138(v/z)^{0\,8}(1 + 50/r) \div d^{0\,2}$$

where $h = BTU$ transferred per sq. ft. internal surface per hr. per $°$ F. mean difference between inner pipe wall and main body of water.

$v =$ velocity of the water, ft. per sec.

$z =$ viscosity of the water *film* in contact with the pipe (see chart).

$r =$ ratio of length of pipe to diam.

$d =$ actual internal pipe diam., in.

VISCOSITY OF WATER—*Bingham*
—*Refrigerating Engg.*

Turbulent flow includes cases where $dv\rho/z$ is greater than 7.6 for steel or wrought-iron pipe, or 9.5 for copper pipe. (ρ = density of water, lb. per cu ft., z = viscosity of the main body of water). The arithmetic mean temperature difference can be used unless the ratio of the differences at the two ends of the apparatus is greater than two, in which case the logarithmic mean (p. 521) should be used. The formula is based on an examination of experiments by *Stanton, Clement* and *Garland,* and by *Bray* and *Sayler* on water flowing through pipes from 0.29 to 0.985 in. internal diameter.

Straight Line Law for Boilers:—*Lucke* points out that in seeking relations between absorption and generation in steam boilers it is necessary to distinguish between real and apparent heat generation. The apparent generation in *BTU* per hr. would be lb. coal fired per hr. multiplied by the heating value per lb. The real heat generated would be lb. fuel fired per hr., times the difference between one and the fraction of fuel lost, times the heating value per pound. The fuel lost would include the carbon in the ashes, in the soot, the unburned gases (carbon monoxide, hydrogen and hydrocarbons), heat required for the evaporation of the moisture in the fuel, and that taken from the hot gases by the walls and the setting between the point of firing and the place where absorption begins. This fraction may be 20%. In considering several reliable boiler tests in which many different kinds of coal were used, he says: "There is no doubt of a linear relation between heat absorbed and *heat available for absorption.*" He gives curves for *Goss'* experiment on a locomotive boiler, the *Bureau of Mines* tests on Heine boilers, *Jacobus'* test at Delray on a Stirling boiler having a heating surface of 23,650 sq. ft., a test of a White automobile flash boiler, and the *U. S. Navy* test of a Hohenstein boiler with liquid fuel. These are grouped in the chart, Fig. H. The straight line relation was found to hold regardless of boiler structure, kind of fuel, or rate of driving. The only difference is to be found in the two constants of the straight line equation, for which there is an adequate explanation. For all except the White flash boiler the line does not pass through zero, but shows an absorption when the generation is zero. This must be a measure of the constant ratio of absorption due to radiant heat, whether any hot gas carries heat to the absorbing surface or not. It is natural that this should differ for different boilers, depending on the exposure of the heating surface to the incandescent fuel and to the brickwork. The rate at which the absorption increases with rate of evolution is dependent on the proportions of the gas passages, which is again a structural feature. Tests at two loads will determine the straight line, from which the relations at any other loads may be taken.

As a general rule, a straight line also results when the heat absorbed is plotted against the *heat apparently generated* in a boiler furnace, or against the rate of combustion. Should it happen that a curve results, this in itself proves a variable fractional furnace heat loss. The percentage of heat lost in a furnace, etc, usually increases as the load increases, so that the curve bends slightly downward from the straight line, as shown in Figure I, reproduced from *Lucke,* for a Hohenstein oil-fired boiler; ordinates are heat absorbed and abscissas for the upper and lower lines are heat available for absorption and heat apparently generated, respectively.

Lucke, in the chart, Fig. J, analyzes the results of a test on an oil-fired Hohenstein boiler. Heating surface efficiency, for practical working ranges of heat generation rates, is a straight line falling with increase in generation. The efficiency of the flue part is independent of the
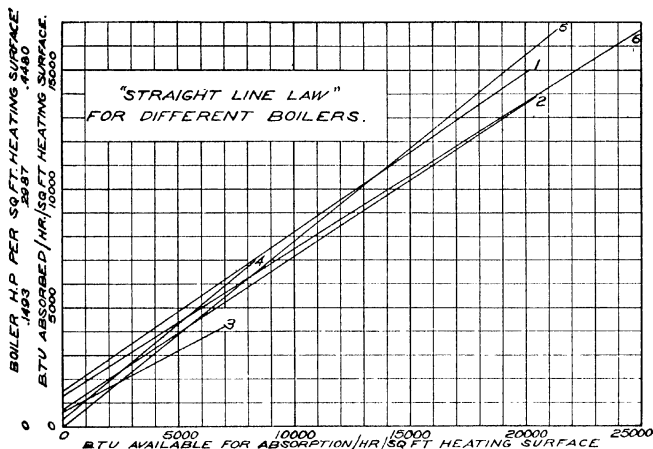
H. RELATION BETWEEN THE HEAT ABSORBED AND THE HEAT
        AVAILABLE FOR ABSORPTION IN DIFFERENT BOILERS

1. Locomotive boiler including superheater.   2. Same exclusive of superheater.
3. Heine boiler.   4   Stirling boiler.   5. White automobile boiler.   6. Hohenstein
boiler.

rate of supply of heat. Therefore, variations in efficiency are probably due
to the fire-box part, which receives radiant heat. The distance between the
heating surface efficiency curve AB and 100% efficiency represents the flue
loss per pound of fuel divided by the generation per pound of fuel or the
calorific power less the furnace and setting loss. For these experiments the
ratio increases with total generation or rate of combustion. Line CD rep-
resents overall boiler efficiency. The vertical distance from it to 100%
represents the sum of losses in flue as sensible heat and the furnace and
setting losses. The vertical distance between AB and CD represents fur-
nace and setting losses. If the two curves are parallel, these losses are con-
stant. If they converge to the right, they must decrease with increased
generation, and if they diverge the losses increase with increased genera-
tion. In this particular case the losses first increase and then decrease,
and are plotted in the line EF. The other curves are as discussed before.

In 1905 Messrs. *Stott* and *Finlay* made complete tests on a 600-HP.
B. & W. boiler equipped with a Roney stoker, at the Interboro Rapid
Transit Co., for a period of over five months. In 1907 they placed another
Roney stoker in the rear of the setting, and ran complete tests over a period
of two months. A baffle was placed above the bottom row of tubes, parallel
with them, extending from the first baffle to the rear header.

The upper curve in Figure L on page 529 shows the relation between
boiler horsepower developed and the quantity of heat presumably liberated
from the furnace per hr. and delivered to the boiler. The quantity of heat
is computed from the weight of coal fired per hr. and the heating value of
1 lb. of coal. This is used in preference to the rate of combustion, because
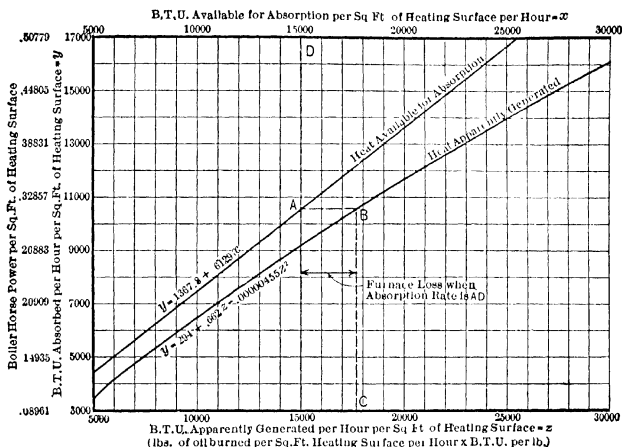
I RELATION BETWEEN HEAT ABSORBED HEAT APPARENTLY
GENERATED, HEAT AVAILABLE AND HEAT LOST IN FURNACE
(OIL FIRED)

the effect of a difference in the quality of coal is thereby eliminated. The tests with a single stoker are represented by the hollow triangles, while the tests with the double stoker are represented by the solid triangles. All the tests lie fairly close to the straight line, indicating that the output of the boiler increased in direct proportion to the quantity of heat delivered to it.

The lower curve is intended to show the effect of heat delivery rate on boiler efficiency, that is, combined efficiency of the boiler and furnace It is difficult to draw a single curve through the points representing the single stoker and the double stoker tests As the quantity of heat liberated increases, the efficiency of the boiler with a single stoker shows a tendency to drop 4 or 5% below that of the double stoker One cause of this is undoubtedly the fact that the fuel on the original front stoker did not burn completely, on account of the small combustion space above that stoker. The addition of the rear stoker more than doubled the combustion space This produces better combustion. Another cause is probably that a greater proportion of the heat is received by radiation It is due to these two that with heavy loads on the boiler the efficiency is higher when two stokers are used. The point to be emphasized is that any fluctuation in the overall efficiency is due more to variation in the efficiency of the furnace than to that of the boiler as a heat absorber. The latter efficiency seems to be practically constant, and independent of the rate of working. Another cause of the drop in efficiency shown in the tests of the single stoker below that shown by the tests of the double stoker is that part of the heat liberated on the rear stoker is absorbed by the boiler by radiation and conduction through the tile roof, so that the gases are not as hot when they enter the tubes as are the products of combustion from the front grate.

B.T U. Apparently Generated per hour per Square Foot of Heating Surface $= Z$
(Pounds of oil burned per Sq Ft Heating Surface per Hr. x B.T.U. per lb)

Per cent of Heat Available for absorption but which was not taken up by Heating Surface but which was discharged to stack

Per cent of Heat Apparently Generated which is lost

Efficiency of Heating Surface

Equation $E_s = \dfrac{1567.8}{Z} + 0.9498$

Efficiency

Boiler

Equation $E_b = \dfrac{294}{Z} + 0.632 - 0.00004552 Z$

Minimum Heating Surface Eff = $100 b$

B.T.U. Available for Absorption per Square Foot of Heating Surface per Hour $= t$

Furnace Efficiency

Equation $E_f = 0.9498$

Available for Absorption entailed

Apparently Generated

Available for Heat Apparently Generated

Heat Available for Absorption

Heat Lost in Furnace by Radiation Unburned Combustibles and etc.

Heat Apparently Generated

Per cent of Apparently Generated Heat which is Lost in Furnace

Equation $e = 16807 Z^{-2} - 40.042 Z^{-1} + 1.07$

B.T.U. Apparently Generated per hour per Square Foot of Heating Surface $= Z$
Pounds of oil burned per Hr. per Sq.Ft. Heating Surface x B.T.U. per lb)

Furnace Efficiency (per cent) $= 100\ E_f$

J. RELATIONS BETWEEN QUANTITIES ENTERING INTO BOILER EFFICIENCY.

MILLIONS OF B.T.U PRESUMABLY LIBERATED PER HOUR

△ SINGLE-STOKER BOILER ▲ DOUBLE-STOKER BOILER

L. SINGLE AND DOUBLE STOKER BOILERS COMPARED

Fig. K, to the right, due to G. H. Gibson, shows the difference between chimney gas and steam temperatures for different rates of evaporation in boilers. It is averaged from about eighty tests of directly fired boilers, and can be used to determine roughly the amount of boiler surface required to reduce the gases to within a given number of degrees of steam temperature. As the temperature to which the gases will be reduced by a given amount of surface depends upon the method of baffling, the velocity of gases, the amount
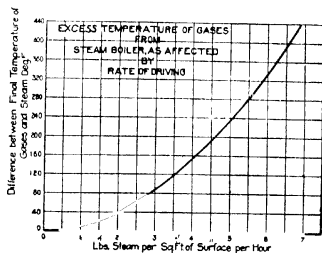
K. EXIT TEMPERATURE AND DRIVING RATE

—Jnl. Engrs. Soc. Pa.

of soot, ashes and scale on the tubes, air inleakage, the amount of boiler surface exposed to direct radiation, etc., the curve is only roughly approximate, but where the results from a given boiler do not lie on the curve it is found that they form a curve that is fairly parallel.

Hans Thoma discusses boiler capacity on the following basis. If the amount of coal burned is doubled, and with it the quantity and the velocity of the gases through the tubes, the temperature remaining constant, the heat transfer, which, disregarding that transferred by radiation, varies as the 0.6 power of the velocity, will be multiplied by $2^{0.6}$. To keep down the stack losses, with double the quantity of gas, the gas velocity must be still further increased, without increasing the amount, by narrowing the boiler, until it equals $2 \times 2^{0.4/0.6} = 2^{1.66}$ times the original velocity. Using the same size and number of water tubes, the gas velocity is increased by reducing the clearance cross-section. This is done by diminishing the number of tubes in parallel in the plane at right angles to the gas flow and increasing those in series; that is, making the conventional sloping-tube boiler narrower and higher. The draft loss due to heat transfer varies as the 1.6 power of the velocity, and entrance and reversal losses as the square; taking 1.8 as the average, the draft loss will vary as $(n^{1.66})^{1.8} = n^{3}$, where n is the number by which the boiler capacity is to be multiplied, with the efficiency maintained constant.
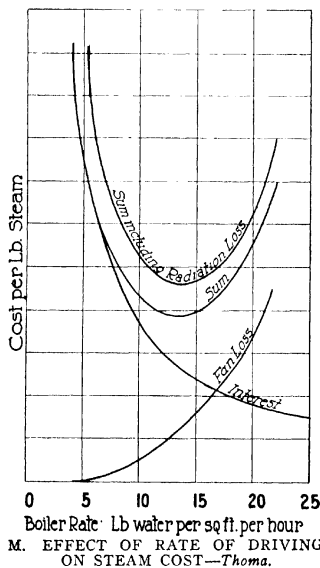
Knowing the cost of boiler heating surface, and the number of hours to be operated per year, the part of the cost of steam per lb. due to interest on investment can be determined for different sizes of boiler, and plotted on the basis of rate of driving boiler, as in Fig. M. The cost of draft, which according to the above varies as the cube of the rate of driving, can be determined, and taking the radiation loss as 3% of the normal rate of steam supply, the "sum" curve shown in the figure can be drawn, representing the part of the cost which varies with the rate of driving. For the problem considered, which was based on 1000 hours' operation per year, the minimum cost was found to be at 14 lb. water per sq. ft. per hr.; for 5000 hr. per year it was found to be at 9 lb. per sq. ft. per hr.

M. EFFECT OF RATE OF DRIVING ON STEAM COST—*Thoma.*
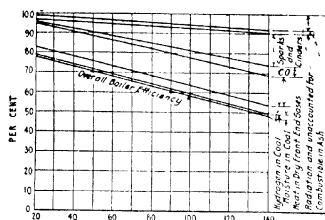
A. VARIATION IN HEAT LOSSES AND BOILER EFFICIENCY
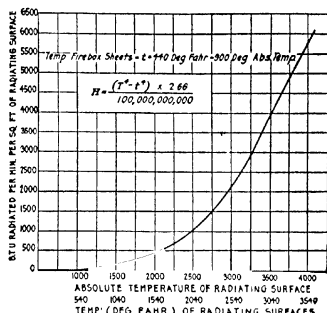
C. HEAT RADIATED TO FIRE-BOX SHEET
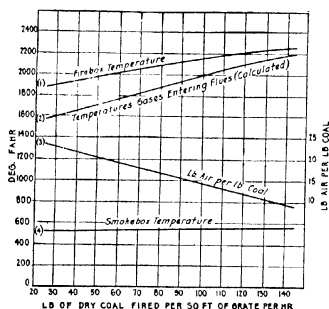
B. VARIATIONS IN GAS TEMPERATURE AND AIR CONSUMED
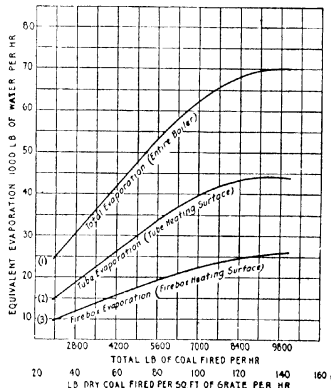
D. EQUIVALENT EVAPORATION SECURED

EFFECTS OF RATE OF DRIVING LOCOMOTIVE BOILER—*A.S.M.E.*

The accompanying charts, *A* and *B*, by *J. T. Anthony,* show the effect of varying the **rate of combustion** of high-volatile Westmoreland coal in a locomotive boiler with 70 sq. ft. of grate, 311 cu. ft. of fire-box volume, 232 sq. ft. of fire-box heating surface and 5280 sq. ft. of flue and superheating surface, the fire-box being without a combustion chamber and equipped with a brick arch. As the rate increased from 30 to 140 lb. of coal, the fire-box temperature rose from 1900° to 2240° F., and the smoke-box

temperature, from 520° to 580° F., while the air supply dropped to 10 lb. per lb. of coal. The soot-covered fire-box heating surface receives practically all its heat by radiation from the luminous fuel bed, flames and brickwork.

Chart *C*, showing radiation to the fire-box sheet, is based on *Stefan's* law, and shows that for a constant sheet temperature of 440° F., a 1540° flame would radiate 400 *BTU*, a 2040° flame 1000 *BTU*, and 3040° flame 4000 *BTU* per min. per sq. ft. of radiating surface; *i.e.*, flame surface.

In chart *D*, showing the equivalent evaporation at various rates of firing, the lower curve, for the work done by the fire-box heating surface, is based on radiation from flames completely filling the box at rates above 80 lb., and half filling it at lower rates. The upper curve, for total evaporation, is based on test data, and the middle curve, for tube heating surface, is the difference of the other two. The fire-box evaporates from 37 to 40% of the total. At the maximum rate shown the 230 sq. ft. of fire-box heating surface transferred 102,400 *BTU* per sq. ft. per hr., by the aid of high fire-box temperature and flame completely filling the box, giving the maximum radiating area.

E. TEMPERATURE DROP AND EVAPORATION IN EACH SECTION

(1) Temp., burning 120 lb./sq. ft./hr.
(2)   "   "   100   "
(3)   "   "   80   "
(4)   "   "   60   "
(5)   "   "   40   "
Evaporations figured for each 1-ft. section of boiler when burning 120 lb./sq. ft. of grate/hr.

In Chart E the performances of the different sections are shown.

SUPERHEATERS

C. H. Baker gives the following formula for **superheater** surface:

$$S = \frac{Ct_s}{2(T - t) - t_s}$$

where S = sq. ft. superheating surface per *B.H.P. generated.*

t_s = degrees of superheat desired.

$T - t$ = temperature difference between gases entering superheater and saturated steam at boiler pressure, ° F.

C = a constant, 6.75 at 100% rating, 4.35 at 200%, 3.35 at 300%.

The form of this equation was suggested by *Bell*, who gave the value of *C* as 10, based on the low forcing rates and steam pressures formerly used. *Baker's* constants are based on tests of a horizontal water tube boiler, stoker fired, with the superheater located at the top of the first pass, and carrying steam at 220 lb. pressure.

TEMPERATURE DIFFERENCE AT ENTRANCE TO SUPER-
HEATER FOR VARIOUS LOCATIONS
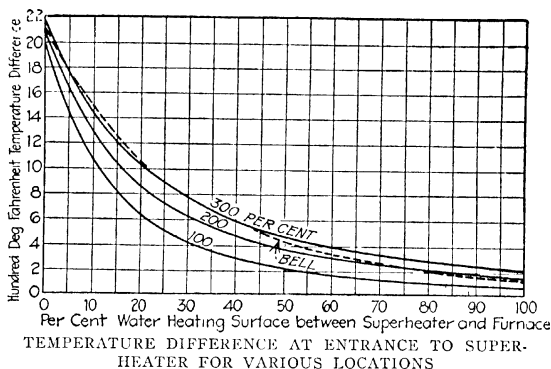
The above chart shows the relation between the location of the super-
heater and the temperature difference $(T - t)$ to be anticipated between the
saturated steam and the gases entering the superheater.

Poensgen offers the following suggestions for improving transmission
in superheaters: The velocity should be greater on the gas side, where the
heat transmission coefficient is less, *i. e*, the tubes should be closely packed.
The gases should also be mixed repeatedly. As the transmission rate is
higher at the entrance to tubes, it is advisable to use a large number of
short, small diameter tubes. Rough surfaces are in general preferable,
and where ribs are used, they should be on the gas side, and lie in the
direction of flow.

Edwin B. Ricketts states that in plants where changes have been
made to high-efficiency combustion processes the superheat is often reduced
by 50%, requiring more surface or the removal of the superheater to a
hotter location. This is due to better absorption in the first boiler pass,
from higher gas temperatures, and to the absence of secondary combus-
tion. With the less efficient apparatus, 1% of CO may pass the first tube
bank and then burn and increase the superheat by 50 or 60° F

The *Superheater Co.* states that when steam is carried from the
turbine for reheating to a secondary superheater in the boiler setting, large
pipes are required, and the temperature of the reheated steam may also
vary greatly. Separately-fired superheaters (oil, gas or coal), with water
tubes in the furnace ahead of the superheater, can be used to advantage in
plants where the auxiliaries are driven electrically from the main switch-
board and there is no exhaust available for heating the water. Reheating
by live steam from the boiler is suitable for high pressures, although the
reheated steam does not reach the live steam temperature. The reheater
requires a comparatively small amount of surface, as the heat absorbed is
the latent heat of the steam, and the transmission coefficient is high, while
easy regulation is secured by the live-steam admission valve. To reheat
to a temperature above that of the saturated live steam, two reheaters
can be used in series, the second receiving superheated live steam. The live
steam can be secured from a special high-pressure boiler.

In "radiation superheaters," usually placed in the rear wall of the combustion chamber, the greater part of the heat is absorbed by radiation rather than by convection. In some of the Lakeside powdered-coal furnaces, the entire steam output flows in parallel streams through horizontal cast steel elements (R, Fig. 1) set in the rear wall. Fireclay fillers between the elements shield them and present a smooth surface toward the flame, while a number of projecting nozzles are used for the removal of soot and cinders. These 17,700-sq. ft. boilers have only 440 sq. ft. of superheater surface, but the surface is designed for transmissions of 33,000 to 48,000 BTU per sq. ft. per hr.

Münzinger mentions as advantages of radiation superheaters, reduction in draft loss, simpler boiler construction, easy location of the necessary superheater surface, omission or reduction of refractory walls, and possibility of augmenting the existing convection superheater in an old boiler. Fig. 2 shows calculated superheater performance as a function of the rate of driving. A convection superheater used alone gives more superheat at increased load, due to higher gas velocity; the degree of superheat in the radiation superheater drops off as the quantity of steam increases, since the rate of heat reception is approximately constant, while if the two are used in series a fairly flat curve is obtained, the maximum variation being 24° F. Fig 3 shows the superheat obtained at the Riverside station with convection superheaters of 2925 sq. ft. and radiation superheaters of only 89 sq. ft., in connection with boilers of 10,438 sq. ft. steaming surface and 6500 sq. ft. economizer surface. The normal throttle pressure was 400 lb. gage, with 250° F. superheat, or 700° F. total temperature.
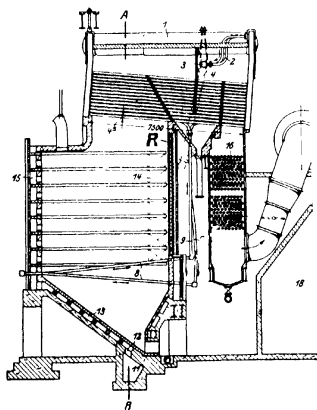
1. LAKESIDE FURNACE WITH RADI-
ATION SUPERHEATER—*Z. d. V.
deut. Ingr.*
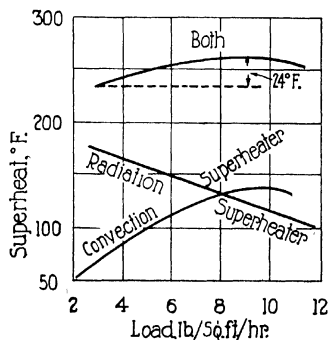
2. SUPERHEATER PERFORMANCE—
Münzinger

BOILER BAFFLING

It is coming to be the general belief that peculiarities of tube arrangement in boilers count for less than proper furnace design and proper baffling.

Kreisinger and *Ray* describe a series of experiments as to the effect of style of baffling on the combustion of Clinchfield coal from Southwestern Virginia. This coal runs over 30% volatile matter, and a large combustion chamber must therefore be provided, although a comparatively small grate area is sufficient to distill the volatile and burn the fixed carbon. The tests showed that such coal could be burned more economically under a water tube boiler, as illustrated in Fig. 4, by the use of horizontal baffling, and that the same arrangement gave good results
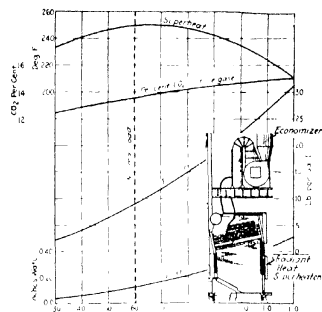
3 PERFORMANCE OF RIVERSIDE COMBINED SUPERHEATERS— *Power*
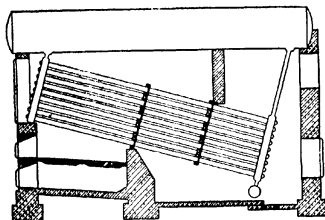
STANDARD BAFFLING
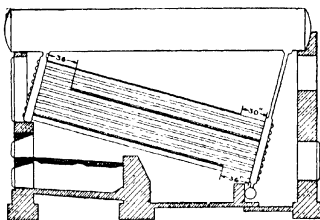
TWO-PASS HORIZONTAL BAFFLING
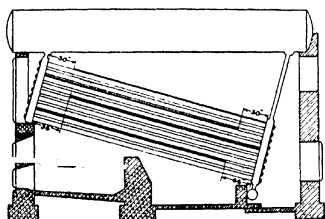
THREE-PASS HORIZONTAL BAFFLING
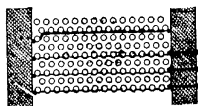
CROSS-SECTION OF 3-PASS BAFFLING

4. SETTINGS TRIED FOR BURNING HIGH VOLATILE COALS—*Power*.

with Pocahontas coal from West Virginia, which is also used in South Carolina, where the tests took place. The arrangements tried were as follows:

1st series: Standard vertical baffling. There were four tests with Clinchfield, and three with Pocahontas coal.

2d series Two-pass horizontal baffling, one row of tubes below the lower baffle, five rows of tubes between the first and second baffles, three rows of tubes below the top baffle. A space behind the bridge wall served as a combustion chamber. The drum surfaces were not used as heating surface. There were four tests with Clinchfield and three tests with Pocahontas coal.

3d series. Three-pass horizontal baffling. Two rows of tubes were below the first baffle, three rows between the first and second baffle, two rows between the second and third, and two rows above the top baffle. The drums were used as heating surface. There were three tests with Clinchfield coal, and two tests with Pocahontas. The table gives a summary of the results obtained

LB WATER EVAPORATED PER LB. COAL.

	Standard Baffle	2-Pass Horz Baffle	3-Pass Horz. Baffle
Pocahontas Coal	7 95	8.54	8.83
Clinchfield Coal	7.49	8.18	8.52

The horizontal baffling shows a much better evaporation with both the Pocahontas and Clinchfield coals The improvement is greater with the Clinchfield coal. The three-pass horizontal baffling gave the highest evaporation The two-pass gave the highest horsepower with the draft available. The two-pass boiler had a slightly lower draft loss through the boiler than did the vertical baffling, while the three-pass boiler had a slightly greater draft loss.

The *Bureau of Mines* made tests at St. Louis in which the gases passed twice through the tube space, without passing under the steam drum. This was accomplished by a special horizontal baffle between the two regular baffles on a Heine boiler. The boiler with this setting showed the greatest heat absorption. Comparing this boiler and one of the standard setting, for a combustion chamber temperature of 2100° F., the standard boiler showed a temperature reduction of 1510°, and the special boiler 1610°. If the temperature of the steam in both boilers is taken as 350° F., the available difference is 2100 — 350, or 1750°, therefore the percentage of available heat used by the standard boiler is 1510/1750, or 86.3%, while that used by the boiler with the special horizontal baffle is 1610/1750, or 92% of the available heat. Averages show that the standard boiler had an actual overall efficiency of 67.4%, and the one with special horizontal baffle had a combined efficiency of 68%.

In 1903, *Abbott* and *Bement,* of the Commonwealth Edison Co., Chicago, made a comparative test on a Heine boiler which they baffled in three different ways, the standard single-pass, a double-pass and a triple-pass arrangement. To form the double-pass setting, a single horizontal baffle was inserted between the tenth and eleventh horizontal rows of tubes. The top baffle was shifted forward so that the gases left the tubes at the rear instead of at the front. The gases came in contact with only the rear

one-fifth of the steam drums. To obtain the triple-pass setting two horizontal baffles were inserted in the standard setting. The first was laid above the 8th row of tubes, and the second above the 14th, the total height of the boiler being 17 rows. The boiler with the standard baffling showed an ordinary boiler efficiency of 57%, the double-pass an efficiency of 62%, and the triple-pass boiler an efficiency of 67%. With the same total pressure drop, the capacity obtained with the double-pass boiler was about 5% higher than that obtained with the standard boiler. With approximately the same total pressure drop, the capacity of the triple-pass was somewhat higher than that of the standard one.

The addition of one or two horizontal baffles rearranges the heating surfaces of the tubes. It places sections of the tube surfaces in series. The section of tubes which the gases enter first was made considerably larger than the succeeding section or sections for the reason that the gases when entering this first section are much hotter and therefore occupy a much larger volume than when passing through the following sections.

The flue-gas temperatures reported in these tests are all too low because the thermometer bulbs were not screened from radiating heat to the "cold" surfaces of the boiler and breeching. As the thermometers were inserted in similar places in the setting, the temperatures can, however, be used for comparison. The average flue-gas temperatures were 635°, 550°, 470° F. for the single, double and triple-pass boilers, respectively. Any further increase of the length of gas passage would reduce the flue-gas temperature very little, and it would hardly pay to lengthen the path of the gases more than by the double or triple pass. Although the figures in the above are to the contrary, it is not to be expected that the increase in efficiency of the triple-pass boiler over the double-pass boiler would be as great as the increase in efficiency of the double-pass over the single-pass boiler, and the gain would be less for each succeeding increase in the length of the gas passage.

The cuts in Figure 5 show the results of a series of tests made on three 500-HP. boilers of the Heine type by *William G Eager*, to determine the arrangement of baffles which would give the highest absorption without restricting capacity for handling overload. Fig *A* represents the original baffle arrangement—encircling tile (as shown in the small sketch) on the lower tubes, with the passage at the back, and V-tile over the rear three-quarters of the top tubes. This was found to permit too rapid a passage of the gases past the tubes, leaving dead sections in the corners shaded, and was remedied by the insertion of an extra baffle as shown in *B*, splitting the gases and exposing all parts of the tubes to their action. Fig. *C* represents the arrangement supplied on one of the boilers, which was new—encircling tile on the lower tubes, a middle baffle extending all the way back, a split upper baffle, and a central vertical wall around the drums, forcing the gases to return and pass out through the upper banks of tubes. This was ineffective on high loads, probably due to an eddy at the point *E*, and was remedied by removing the vertical wall and extending the upper baffle forward, as shown in Fig. *D*. This latter arrangement was finally accepted as the most satisfactory arrangement for all three boilers.

CASE A

CASE B

CASE C

CASE D

Encircling Tile (Lower)

Cast Iron (Middle)

V-Tile (Upper)

TYPES OF BAFFLES USED
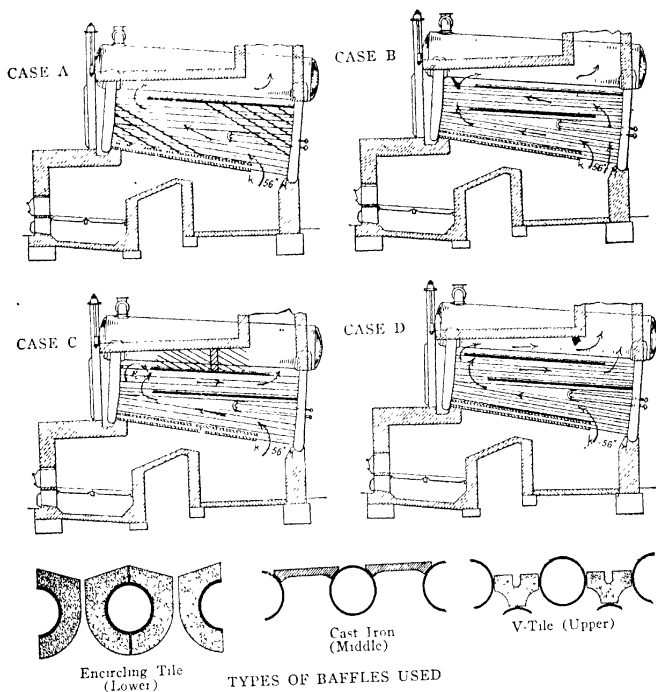
5   EXPERIMENTS ON BAFFLING HEINE BOILER   (P. 537)
                                                    —A S M E.

Dean and Kreisinger describe a series of tests made by the Bureau of Mines on special water-tube boilers for marine use. With the original three-pass baffles, shown in Fig. A, considerable combustible gas escaped from the furnace, due to insufficient supply and poor mixing of air. They state that no free oxygen can be forced through a level 5-in. bed in a hand-fired furnace, regardless of the ash-pit pressure. If holes are present, they are large before firing, and nearly absent immediately after firing, when a large amount of air is required, so that air should be admitted through fire-door or bridge wall, in small jets close to the fuel bed, making use of as much as possible of the space above the fuel bed for mixing
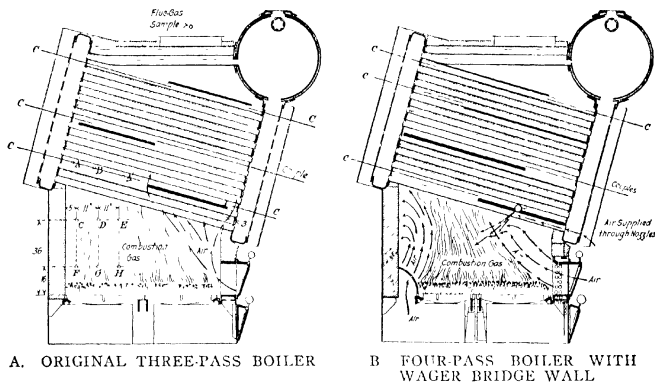
A. ORIGINAL THREE-PASS BOILER   B FOUR-PASS BOILER WITH
                                         WAGER BRIDGE WALL

MARINE WATER-TUBE BOILERS TESTED FOR AIR ADMIXTURE
                                              —A S.M E.

and combustion. Accordingly, 240 ½-in holes were made in the firing
doors and frames, affording in connection with cracks a total opening of
48 sq. in.; the small opening between the first baffle and the front water
leg was closed, and the baffle was extended, reducing the gas passage
between end of baffle and rear water leg to 36 in in a tube length of 91½
in., and forcing the air to flow farther back and mix with combustible
gases. A *Wager* bridge wall, shown in the four-pass diagram, Fig. B,
was built against the rear wall, consisting of cast-iron grate bars with
³⁄₁₆-in. slots for air admission, with a slot area of 64 sq in, the total air
opening through doors and bridge wall being 2% of the grate area   In
Chart C, the portion marked "Tests Nos 10, 11 and 12" shows gas analyses
at three points 16 in. above grate, at three points 36 in. above the grate,
and at points in the first pass, all for the improved three-pass arrangement,
with air supply through firing door and *Wager* bridge wall. The sample
taken at the point H (Fig. A), 27 in. from the rear wall and 16 in. above
grate, shows 7½% C (combustible gases), only 2½% oxygen, and 13%
CO_2, the air from the bridge wall not having penetrated so far forward
at this level, while point E. above it, shows less than 4% combustible,
indicating that the air from the bridge wall, in rising 20 in., has penetrated
to a considerable distance into the stream of combustible rising from the
fuel bed. In the first pass, the composition at the two points A and B is
nearly uniform, showing that the bridge-wall air mixed well and did not
pass out in a separate stream. The second and third groups of tests (Nos.
13 to 16) were made with a solid brick bridge wall similar in shape to
the *Wager* wall, and the furnace gases are low in oxygen and high in
combustible, due to insufficient air supply. While the stack gases do con-
tain oxygen, the combustible also present in them shows that the air
which found its way into the furnace was not close enough to the fuel
bed to effect complete combustion. In the third group, the sample taken
at the point A', 30 in. from the rear water leg, shows more free oxygen
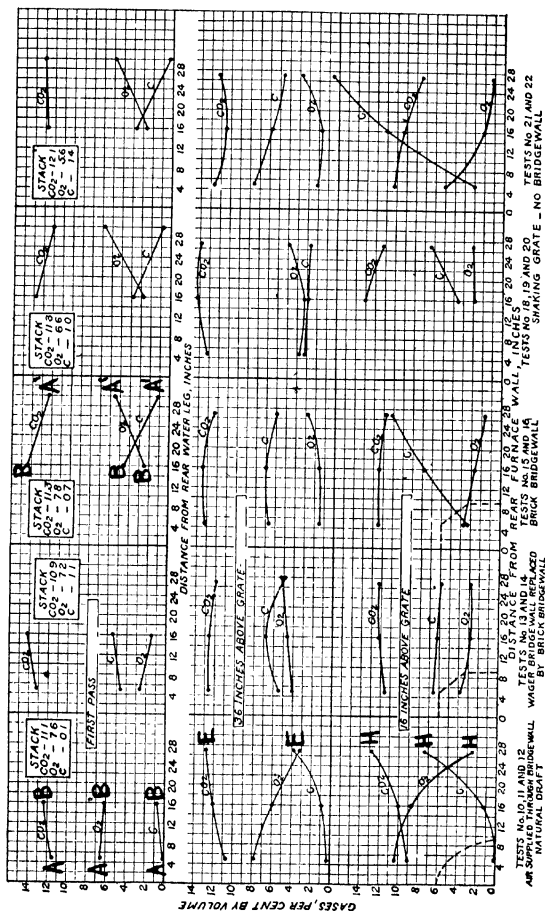
C. GAS COMPOSITION AT VARIOUS POINTS OF THREE-PASS MARINE
WATER-TUBE BOILER
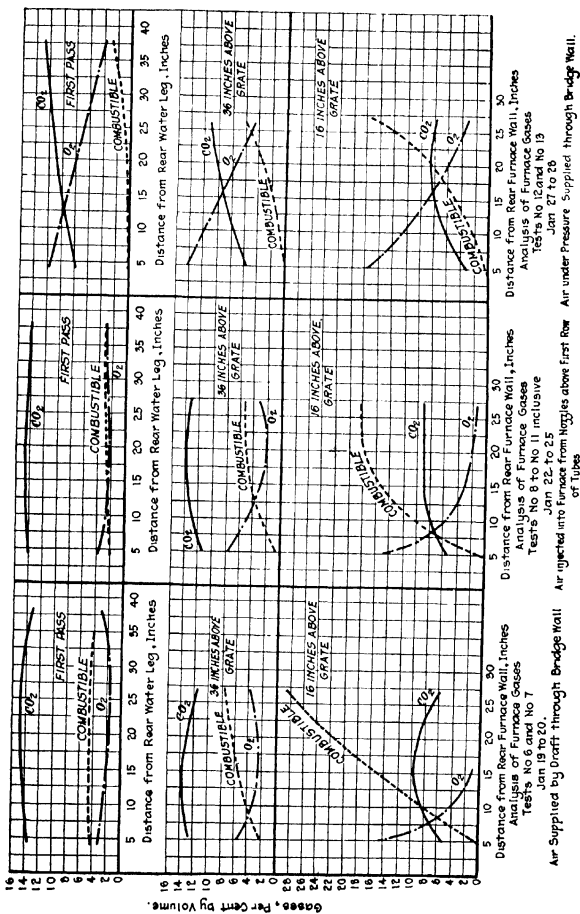
—A S.M.E.

D. GAS COMPOSITION AT DIFFERENT POINTS IN FOUR-PASS MARINE
WATER-TUBE BOILER

—A.S.M.E.

than at the point B, further from firing door. The fourth and fifth groups of tests were made with a shaking grate and no bridge wall, and show clearly the advantage of air admission through a slotted bridge wall. The lower samples show that a small quantity of air passed into the furnace close to the rear wall, but the combustible remained high even into the furnace, and in spite of combustion in the passes, the stack gas contained over 1% combustible

Chart D shows three groups of tests on the four-pass boiler (Fig. B), all with *Wager* bridge wall. The first group was with natural draft, secondary air entering through the firing door and bridge wall. The 16-in. high samples show the effect of the bridge-wall air only at the point 5 in. from the rear, while the 36-in and first-pass samples show fairly uniform distribution but insufficient quantity of air. Apparently the fuel bed was too thick, and a thinner bed would have given less combustible in the first pass In the second group the air supply was augmented from a 3½ in. pipe between the second and third tube rows (Fig. B), containing seventeen ½-in nozzles and supplied with air under 2-in. pressure to force the air from the door into the stream arising from the fuel bed. The combustible in the samples in the first pass was a little too high, indicating that not quite enough air was admitted. In the third group the air through the bridge wall was admitted under ⅜ in. pressure, but tended to flow in a separate stream close to the rear wall, the excess in the first pass decreasing toward the front The admission of bridge-wall air under pressure was found to be on the whole undesirable in this type of furnace While the air pipe used in the second group of tests favors complete combustion, it entails undesirable complications in the boiler plants of ships, and the method followed in the first group of four-pass tests is satisfactory when attention is given to the proper thickness of fuel bed next to the bridge wall.

Paul W. Thompson describes a series of tests on a Stirling boiler with 23,654 sq ft. heating surface and 2996 sq. ft. superheater surface, to determine the best form of baffling. The boiler was fired by two 13-retort, 2-ram underfeed stokers, and tests, Figures E and F, pages 543 and 544, were made with coal from Harlan, Kentucky, containing approximately 12500 BTU per lb. as fired. As originally baffled the highest efficiency was 79% at 160% of rating A special washing of the tube surface, in addition to the regular soot-blowing, was found to increase the efficiencies by about 0.75%. The "A" baffling arrangement showed no improvement over the original arrangement except that the draft at the damper was reduced about 33%. With the "B" arrangement an average increase in superheat of 20° F. was obtained, flue-gas temperature reduced about 70° F., and draft about 38% less than with the original baffling. There was little difference between the "B" and "C" arrangements, and as the "B" was simpler and gave a slightly higher superheat, this arrangement, slightly modified, was adopted for the remaining boilers of the plant The vertical baffle has been shortened about 6 in., and the cross baffles at the top inclined upward at about 35° from the front baffle A study of the heat absorbed in the different passes of the boiler indicated that a re-arrangement of tubes would be beneficial, and for this reason the new boilers subsequently installed have in cross section but five tubes between the upper center drum and each mud drum, and ten tubes between each mud drum and the upper drum directly above. The baffling is similar to
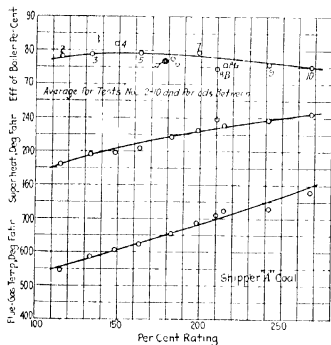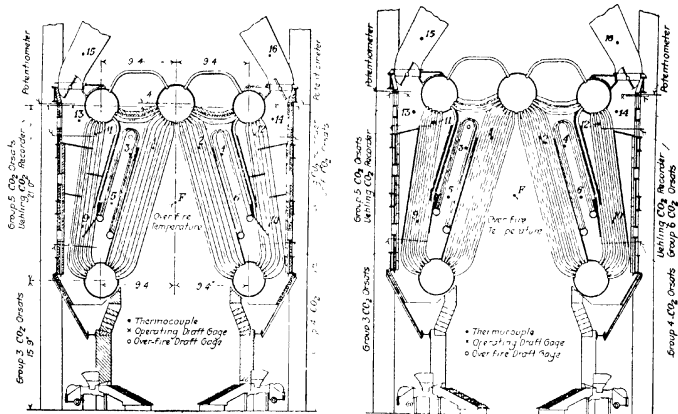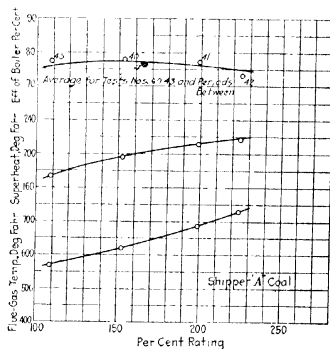
ORIGINAL ARRANGEMENT   "A" BAFFLE ARRANGEMENT

E   REBAFFLING OF STIRLING BOILER —*A S M E*

"B," except that there are two vertical baffles in each rear bank, which direct the gases in three vertical passes after they leave the superheater pass.

A. W. Patterson presents the illustrations on page 545 of baffle and furnace design intended to secure long life for the furnace and low maintenance costs. Fig. 1 shows a setting used on 1000 or 750 HP. boilers. The combined bridge and back wall has a backward slope, giving rigidity and reflecting the heat against the tubes, while the front wall is

in two parts, relieving the brickwork of weight. The entire roof of the
furnace is heat-absorbing, and the entering gas velocity is low. Fig. 2
shows a low-set boiler adapted to oil firing by inserting the furnace in
the foundations, the bridge wall having a concrete pier and the side walls
having protecting piers of insulating material and brickwork. The baffle
design was made to conform to the furnace by a combination of a flat
shelf and inclined front baffle, a soot pocket being secured behind the
bridge wall. Fig. 3 shows a 1500 HP. boiler in which the original front
baffle was as shown dotted, dropping to a vertical bridge wall. Slagging
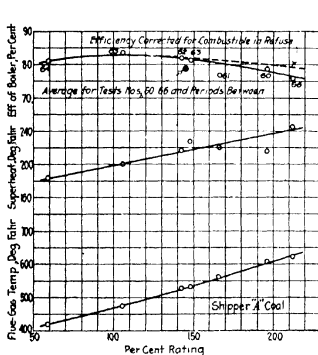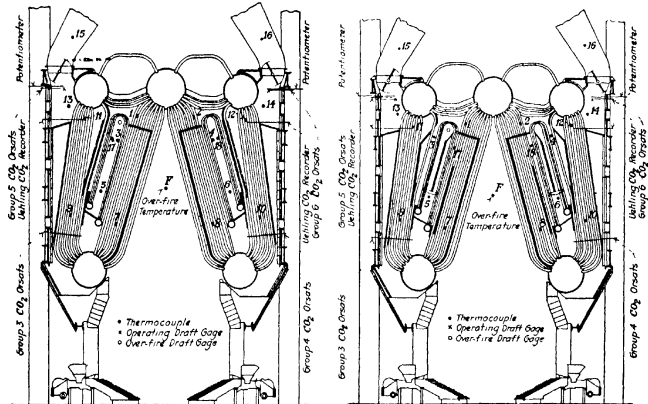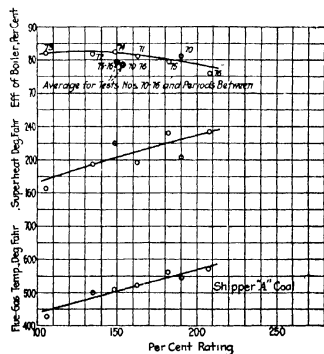
"B" BAFFLE ARRANGEMENT   "C" BAFFLE ARRANGEMENT

F. REBAFFLING OF STIRLING BOILER—*A.S.M.E.*
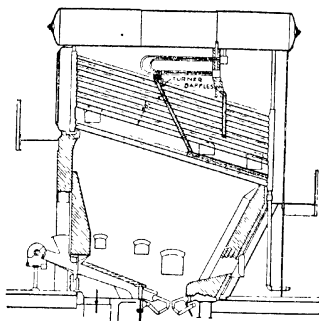
1. SETTING WITH HIGH ABSORP-
   TION OF RADIANT HEAT
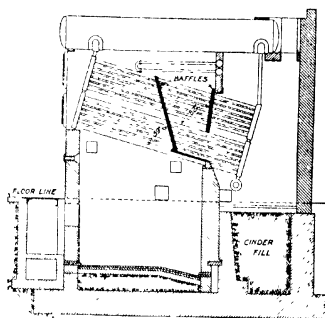
2. SETTING REDESIGNED FOR OIL
   BURNING
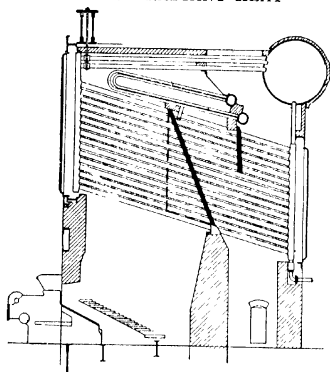
3. SETTING REBAFFLED TO
   PREVENT SLAGGING
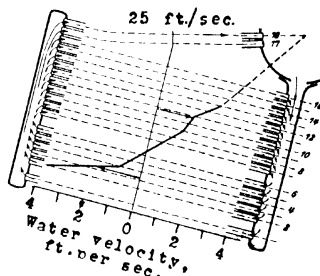
4. CIRCULATION IN MARINE
   BOILER—Z d. V. d. I.

on the tubes caused positive pressure in this furnace, with deterioration of the front wall. The revised baffle arrangement increased the entrance to the first pass about 50%, and gave less restriction around the rear baffle, while a slight back corbeling was given to the bridge wall to provide rigidity. The lower gas velocity and furnace temperature eliminated slagging and the effects of pressure, stoker repairs were reduced, and the boiler shown was kept on the line 86% of the time as compared with 70% for other boilers in the plant.

Münzinger calls attention to U. S. Government tests on water-tube marine boilers, which showed that the water flowed toward the front leg in the six lower rows of tubes, and toward the back leg in the upper rows, and says that previous knowledge of this fact in Germany was the reason

for the usual limitation to eight tube-rows in that country, so that the water would always flow up in the tubes. He states, however, that with properly designed boilers the reversal of direction is not objectionable, there being two parallel water streams, one toward the upper drum, carrying the steam liberated in the tubes, and one through the upper rows of water tubes. See Fig. 4.

Osborn Monnett says that in solving the smoke problem in Chicago he was often forced to employ horizontal baffling. Tests proved that efficiency and capacity were not lost. However, with horizontal baffling there is usually a greater draft loss, and the factor of available draft must be given consideration

Condition of Baffles.—The baffling should always be inspected when the boiler is shut down for cleaning and repairs They should be examined for the smallest cracks and these cemented tightly Concentration of flow gradually forces a larger opening until failure of the baffle results. The installation of pyrometers in the top of the last pass, fitted with recording devices if possible, is a ready safeguard against operating for any length of time with the baffles out of order The effect of a broken baffle is shown by the temperatures taken on a 500-HP Stirling boiler. The temperature over the fire was 2462° F With baffles in good shape, the temperature at the first pass was 1148°, and at the top of the last pass 545°. With a defective baffle the temperature at the top of the first pass dropped to 662°, due to non-circulation of gases at this point, while that at the top of the last pass was 1778° The efficiency had dropped from 78 8 to 28 2%. A hole was discovered in the center of the first baffle 32 by 28 in.

ECONOMIZERS

The old-style cast iron economizer was arranged for the water to enter all the tubes at the bottom and leave at the top, while the gases pass at right angles to them. The equation on page 514 is used in such cases to determine the economizer surface Where the gases have a great temperature drop the economizer is more efficient if the sections of tubes are connected in series, or at least if groups are connected in series, with the gas flowing opposite to the water, that is, countercurrent. For determining the surface for countercurrent flow, where the temperatures of both fluids change, the differential equation $(T - t) \, RdS = - WcdT$, page 515, can be integrated as follows:

$$S = \frac{Wc}{R} \left[\frac{T_1 - T_2}{(T_1 - t_1) - (T_2 - t_2)} \right] \log_e \left(\frac{T_1 - t_1}{T_2 - t_2} \right)$$

$t_1 =$ water temperature at hot end of the economizer,
$t_2 =$ water temperature at cold end of economizer,
Other symbols as on page 515.

The transfer rate R, or coefficient of transmission, for the old style *Green* economizers, is given by G. H. Gibson in Fig. A, based on over 200 tests of standard (not countercurrent) economizers having vertical cast-iron tubes of $4\frac{9}{16}$ in. diameter spaced on 8 in. centers in the section and $7\frac{1}{4}$ in. centers section to section. The transfer rate R is a function of rate of gas flow and of the temperature of the gases in the economizer. The rate of gas flow is plotted as total lb. through the economizer per sec., divided by the number of lineal ft. of tube in one section, *i.e.*, if each section consists of ten 10-ft. tubes, there are 100 ft. of tube per section.

COEFFICIENT OF HEAT TRANSMISSION IN ECONOMIZER AS AFFECTED BY RATE OF GAS FLOW AND MEAN TEMPERATURE OF GASES
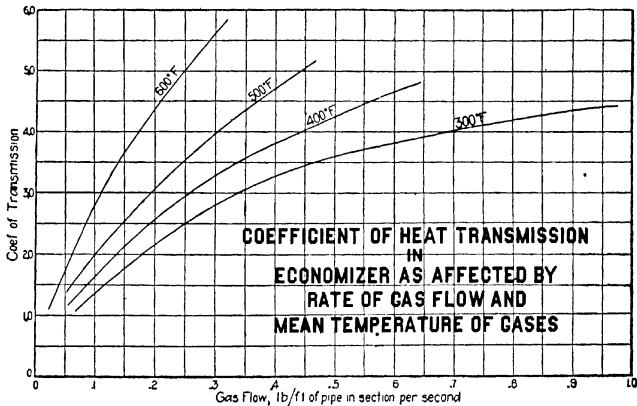
A. COEFFICIENT OF HEAT TRANSMISSION IN ECONOMIZER AS AFFECTED BY RATE OF GAS FLOW AND MEAN TEMPERATURE OF GASES

A straight line relation holds for the rate of heat recovery in the econo-
mizer, which increases directly with the load on the boiler with which it ,
is connected. In the series of economizer tests given in Fig. B by *Gibson*,
the heat recovery with increasing load seems to be less than with decreasing
load. This is because its determination depends on measurement of the
temperature of water leaving the economizer and there is a lag between
the absorption and its measurement, due to the volume of stored water.
After determining one point for steady load, by test or computation, and
drawing a straight line through it and zero, the rate of recovery in the
given apparatus at other loads can be read off at once.

The 1921 Prime Movers Committee Report states that except as
regards corrosion troubles, wrought-steel construction is more suitable for
high pressure economizers than is cast iron, the maximum pressure for the
latter being stated at from 150 lb to 350 lb, many engineers favoring 250
lb. It is recommended that preliminary tests of cast iron economizers be
kept well within the elastic limit of the material, and that all tubes be
carefully gaged before the row is assembled in the header, as the presence
of one or two oversize tubes may cause the header to split. From the point
of view of corrosion, less external and internal pitting is to be expected
with cast iron, while wrought-steel economizers are in general less bulky
and, especially for the higher pressures, less expensive and more easily
housed with the boiler in a single setting, reducing leakage and radiation
losses. It is believed that steel economizers show a better heat transfer
than cast iron, the tubes being frequently 2 in. instead of 4 or 5 in. Manu-
facturers of cast iron economizers are inclined either to favor soot scrapers
or to put them on a par with blowers, while operators are divided in
opinion, but probably more than half the new installations are equipped
with blowers.
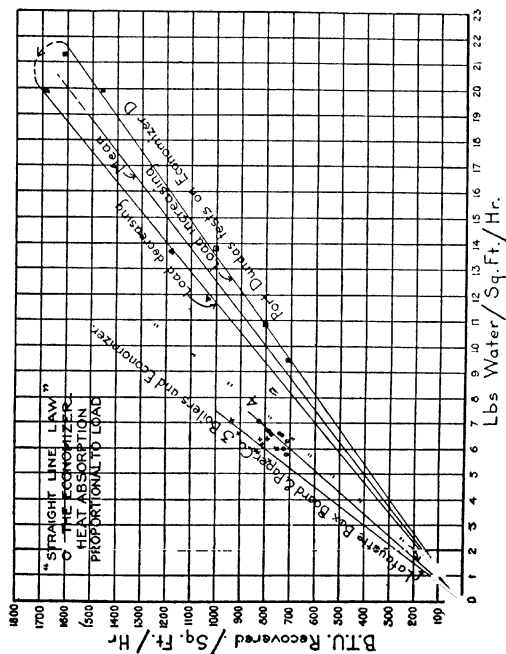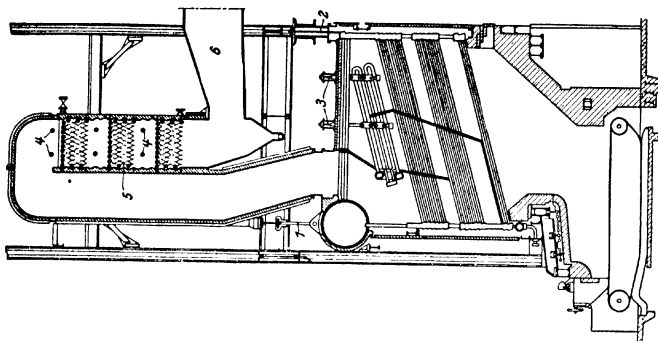
B. "STRAIGHT LINE LAW" OF ECONOMIZER

ECONOMIZER PLACED ABOVE
BOILER—Z. d. V. d. I.
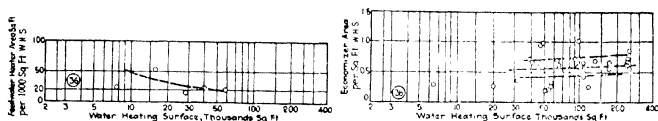
HEATER AND ECONOMIZER AREA IN MODERN PLANTS -- *Power*

The above charts, by *John G Fairchild*, show the feed-water heater and economizer area, both in relation to boiler heating surface, in a number of modern plants.

AIR HEATERS

Air preheaters, long used in marine work, are now being applied to stationary practice, for the recovery of the sensible heat contained in flue gases *Emile Prat* gives the following for average practice

$$L = 0.37 \; T/C, \text{ where}$$

$L = \%$ of heat lost in flue gases
$T =$ temperature difference between gases sent to stack and boiler-room air, ° F
$C = \%$ of CO_2 in flue gases.

On this basis, for gases escaping at 570° F., air at 70° F, 8% CO_2, the loss would be 23%; but if the gases were cooled to 320° F in an air heater, which should bring the air up to 300° F, the stack loss would be reduced to 11 5% In addition to the theoretical gain by returning the heat to the furnace, the higher furnace temperature should lead to more efficient combustion, with less carbon in the ash, with the use of less excess air; and to better heat transfer, both by radiation and from contact of gas with metal, so that the gases leave the tubes at a *lower* temperature than when the furnace is supplied with unheated air *S Utting* gives the accompanying Fig. 1, in which the upper boundary of the shaded area represents the gas temperature at various points in its path through the tubes, expressed as

1. GAS TEMPERATURES WITH HEATED AND UNHEATED AIR

fraction of boiler surface passed over, for a furnace receiving unheated air. The horizontal 380° line is water temperature. For the same rate of driving, the total heat transferred, and hence the area under the curve, will be the same, but with higher entrance temperature, and the two plotted curves will cross. While this assumes that the coefficient of heat transfer is independent of gas velocity, which is not strictly true, experience shows that the reasoning is correct and that the drop in boiler-exit temperature is about 20% of the increase in furnace temperature. If the latter is raised 100° F., the final temperature will drop 20° F, representing say 2% fuel saving in addition to the heat recovered in the heater. Air heaters can be used in series with economizers, either before or after, but it is claimed that where they are used to replace economizers, a saving is effected in space, weight and cost, and that feed water is more advantageously heated by auxiliary exhaust or bled steam.

Jos. G Worker lists the following effects of the application of preheated air to stoker operation:

1. The efficiency of the modern stoker and boiler and superheater at 200% boiler rating will be 83%.

2. The efficiency of the modern stoker, boiler, superheater and preheater at 200% boiler rating will be 90%

3. The modern stoker can be operated at 500% boiler rating continuously.

4. The modern stoker can be operated to handle peaks of short duration up to 700% boiler rating

5 The CO_2 performance with preheated air will range from 15½% at 250% boiler rating to 16½% at 350% rating and above

6. Combustible loss in refuse will be less than 0 7 of 1% of BTU in coal or 7% combustible in refuse

7. 80,000 BTU for maximum rating can be liberated per cubic foot of furnace volume per hour.

8. It is easier to burn coal which might otherwise smoke, entirely without smoke

9. Elimination of continual cooling and heating of fine particles of ash by introduction of heated air in refuse, resulting in easier handling of refuse of fuel bed

10. Preheated air in effect lengthens the stoker fuel bed by decreasing the amount of space required for drying the coal, making more effective the actual carbon burning zone.

Wilhelm Gumz gives in Fig. B, p. 559, the increased efficiency resulting from preheating combustion air from 68° to 428° F. for various flue gas and combustion temperatures.

The *C E C* (Combustion Engineering Corporation) *Air Preheater* follows the general design of the Usco heater, and contains a series of plates dividing the apparatus into alternate parallel passages for air (1 in. thick) and flue gas (1¼ in thick). (See page 557.) The two flows pass in opposite directions, so that the metal in contact with the hottest gases has the hottest air on the other side of it, and the temperature difference remains practically constant. The draft loss is given as less than 0.5 in. when handling gas at the rate of 6000 lb. per hr. per sq. ft. cross-sectional area. The greater density of the air and more restricted path for it makes it desirable to draw the air through the heater by the same fan which is used to force it to the furnace.

2. HOWDEN-LJUNGSTRÖM AIR PRE-
HEATER—*Power Plant Engg*
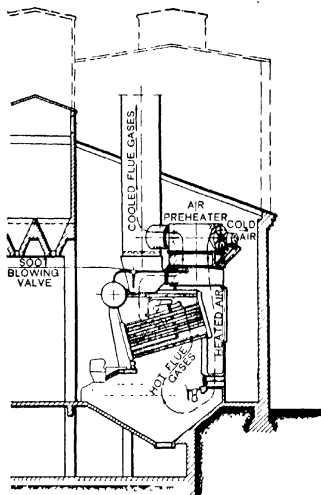
3. AIR PREHEATER SET ABOVE
BOILER
—*Blast Furnace & Steel Plant.*

The *Howden-Ljungström Air Preheater* is divided into two semi-cylindrical sections; air is drawn into one by a fan at the top and passes out at the bottom, while hot gases pass up through the other and are withdrawn by another fan on the same shaft. Heat transfer is not through metallic surfaces, but is effected by a slowly-rotating "porous" drum, in which the spaces between radial blades are filled with corrugated and plain sheets forming arcs of circles concentric with the drum axis. Air and gas flow without obstruction through the vertical passages of this honeycomb, the metal work taking up heat while in the gas half and giving it off while in the air section, much as does the brickwork of a regenerative furnace. If the drum were rotated with infinite velocity the temperature heads causing heat transfer from gas to metal and from metal to air would be the same as in a counter-current air heater with stationary tubes, the temperature gradient through the metal of the latter being negligible. With finite velocity the temperature head would in general be less. Fig. 3 shows arrangement for the *Dalmarnock Power Station, Glasgow, Scotland,* using an air preheater over a B. & W. boiler of 6948 sq. ft. heating surface and 2452 sq. ft. superheater surface, capacity 50,000 lb. steam per hr., at 275 lb. and 291° F. superheat, fired by chain grate of 273 sq. ft. area. The dotted lines represent the additional height that would have been required for water economizer.

fraction of boiler surface passed over, for a furnace receiving unheated air. The horizontal 380° line is water temperature. For the same rate of driving, the total heat transferred, and hence the area under the curve, will be the same, but with higher entrance temperature, and the two plotted curves will cross. While this assumes that the coefficient of heat transfer is independent of gas velocity, which is not strictly true, experience shows that the reasoning is correct and that the drop in boiler-exit temperature is about 20% of the increase in furnace temperature. If the latter is raised 100° F., the final temperature will drop 20° F, representing say 2% fuel saving in addition to the heat recovered in the heater. Air heaters can be used in series with economizers, either before or after, but it is claimed that where they are used to replace economizers, a saving is effected in space, weight and cost, and that feed water is more advantageously heated by auxiliary exhaust or bled steam.

Jos. G Worker lists the following effects of the application of preheated air to stoker operation:

1. The efficiency of the modern stoker and boiler and superheater at 200% boiler rating will be 83%.

2. The efficiency of the modern stoker, boiler, superheater and preheater at 200% boiler rating will be 90%

3. The modern stoker can be operated at 500% boiler rating continuously.

4. The modern stoker can be operated to handle peaks of short duration up to 700% boiler rating

5   The CO_2 performance with preheated air will range from 15½% at 250% boiler rating to 16½% at 350% rating and above

6. Combustible loss in refuse will be less than 07 of 1% of BTU in coal or 7% combustible in refuse

7. 80,000 BTU for maximum rating can be liberated per cubic foot of furnace volume per hour.

8. It is easier to burn coal which might otherwise smoke, entirely without smoke

9. Elimination of continual cooling and heating of fine particles of ash by introduction of heated air in refuse, resulting in easier handling of refuse of fuel bed

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The C E C (Combustion Engineering Corporation) Air Preheater follows the general design of the Usco heater, and contains a series of plates dividing the apparatus into alternate parallel passages for air (1 in. thick) and flue gas (1¼ in. thick). (See page 557.) The two flows pass in opposite directions, so that the metal in contact with the hottest gases has the hottest air on the other side of it, and the temperature difference remains practically constant. The draft loss is given as less than 0.5 in. when handling gas at the rate of 6000 lb. per hr. per sq. ft. cross-sectional area. The greater density of the air and more restricted path for it makes it desirable to draw the air through the heater by the same fan which is used to force it to the furnace.

4. THERMIX AIR PREHEATER
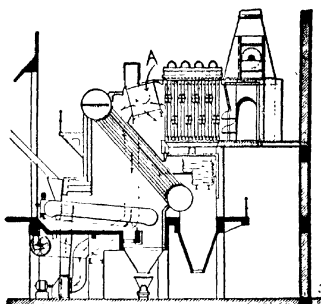
5. WATER-TUBE BOILER USING ECONOMIZER AND 3,000-SQ. FT. AIR HEATER—*Power*

The path of the flue gases is shown by the wavy arrows and that of the air by the dotted arrows

The Thermix Air Preheater consists of a pile of thin rectangular plates held apart by helical wire spacers and so arranged that air and gas may pass through alternate spaces The gas usually passes directly through, but the air passages have division pieces extending halfway into the casing so that the air penetrates the apparatus before being reversed, its general course being semi-circular. Fig 5 shows an installation in which the flue gases pass from the boiler to a *Thermix* preheater *A*, and issue through the side and bottom to a water economizer, while the air follows the semi-circular path shown through the preheater, and then flows down through the duct to the fan feeding the furnace. Tests by the *Paris Steam Users Association* on another installation showed the following results:

TEST OF BOILER WITH AND WITHOUT AIR HEATER

Boiler heating surface, sq. ft..		825
Superheating surface, sq ft		380
Grate area, sq. ft		38.5
Air heater used.....	Yes	No
Date of test.......	Jan 21, '21	Jan. 22, '21
Duration of test...	7 hr.-50 min.	8 hr.

Fuel:

Calorific value of dry coal, *BTU* per lb........	13,400	14,200
Moisture, in coal as fired, %..	2.7	2.5
Volatile, in dry sample, %......	10.95	14.1
Ash, in dry sample, %........................	10 5	8.25
Fixed carbon, in dry sample, %..............	78.55	77.65

Pressures, Temperatures, etc.:

Feed water temperature, ° F....................	45.5	45.5
Boiler pressure, gage, lb. per sq. in............	67	67

Temperature of steam leaving superheater, ° F..	428	406
Temperature of air at inlet to air heater, ° F...	56	...
Temperature of air supplied to boiler, ° F......	194	77
Temperature of flue gas at boiler uptake, ° F...	....	554—590
Temperature of flue gas at air-heater inlet, ° F.	572—608	....
Temperature of flue gas at air-heater outlet, ° F.	428—472	....
CO_2 in flue gas, %............................	10 0	7.87
O_2 in flue gas, %.............................	8.0	9.37
Draft at inlet to heater fan, in.................	0.28	....
Pressure at discharge from heater fan, in......	1.18	....
Draft on boiler grate, in.......................	0 05	0 03
Draft before air heater, in.....................	0 14	0.10
Draft after air heater, in	0.40	0.44
Weights:		
Dry coal burned per hour, lb..................	567	531
Dry coal burned per sq ft. of grate, per hr., lb.	14 7	13.8
Feed water supplied per hour, lb	4,300	3,736
Saturated steam per hour to feed pump, lb.....	154	133
Superheated steam produced per hour, lb.......	4,146	3,603
Water evaporated per hr. per sq. ft. heating surface, lb.	5.21	4.53
Evaporation and Efficiency:		
Saturated steam supplied to feed pump per lb. of dry coal burned, lb......................	0.27	0.25
Superheated steam produced per lb. dry coal, lb.	7 30	6.79
Boiler efficiency (allowing for feed pump).....	66.8	58.1
Boiler efficiency (not allowing for feed pump)..	69.2	60.2
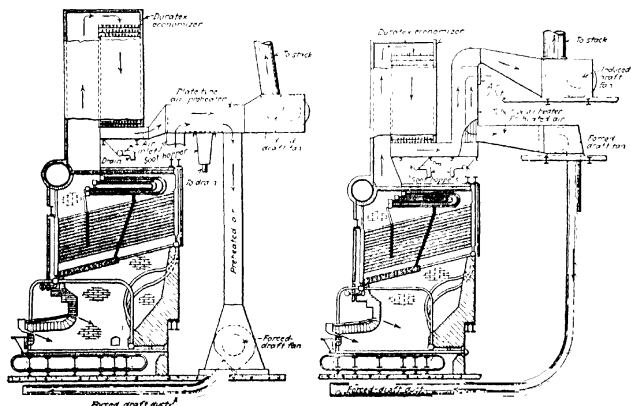
**BOILER NO. 12 PLATE-TYPE HEATER   BOILER NO. 16 TUBE-TYPE HEATER
AIR PREHEATERS AT CALUMET STATION—*Power***

Edwin B. Ricketts gives the following summary of tests on recent installations of air preheaters:

SUMMARY OF AIR HEATER DATA

(Figures given are averages of tests)

Location	United States				Foreign		
	Colfax Sta, Duquesne Light Co.	Boiler No 12, Calumet Sta, Commonwealth Edison Co	Boiler No 16, Calumet Sta	Boiler No 15, Northeast Sta, Kansas City Light & Power Co	England	Rörges, France, Benost & Co	The Hague, Holland, Hague Municipal Power Plant
Manufacturer	Combustion Eng'g Co	Combustion Eng'g Co	Babcock & Wilcox Co	Combustion Eng'g Co	Jas Howden & Co	Maison Emle Prat Daniel	Maison Emle Prat Daniel
Type	"Plate"	"Plate"	"Tube"	"Plate"	Howden-Ljungstrom	"Thermix"	"Thermix"
Boiler surface, sq. ft	22,914	15,089	15,089	12,743	900	1,960	6,725
Superheater surface, sq. ft.	2,999	4,052	4,052	5,748	.....	.....	.....
Economizer surface, sq. ft	.....	9,700	9,700	8,100	.....	.....	5,130
Air heater surface, sq. ft	11,200	9,000	8,954	9,600	.....	1,506	7,525
Temp. of gas, °F, air-heater inlet	482	335.8	291.4	295	583	500	392
Temp. of gas, °F, air-heater outlet	303	269.8	220.4	224	232	.....	316.4
Temp. of air, °F., air-heater inlet	108	71.3	65.3	75	.....	62.6	78.8
Temp. of air, °F. air-heater outlet	229	161.3	155.1	142	436	163.4	167
Weight of gas through air heater, lb. per hour	171,067	175,600	......	......	......	......	......
Gain in efficiency due to heat absorption, %	2.8	1.65	1.72	1.93	8.6	2.7	2.2
Gain in efficiency due to better combustion %	3.14						
BTU per sq. ft per hour per °F. difference	2.95	1.63		1.2	13.4	10.3	4.3

The Colfax Station is illustrated and described on pp. 556-7, the Calumet installations are shown on page 554.

C. W. E. Clarke describes an air heater, Fig. 1, installed above the boiler in an existing setting at the Colfax Station of the Duquesne Light Co. The C E C preheater consisted of two heating elements, total 11,200 sq. ft., placed back to back, the central vertical third of the heater being occupied by a by-pass for the flue gases, used when the preheater is cut out. The gases ascend through the preheater by natural draft, while the air passes down to a suction fan from which it is fed to the stoker wind box by the same duct formerly used for the forced-draft fan. The preheater is designed to supply sufficient air at 235° F to take care of an equivalent evaporation of 144,000 lb. water per hr., which is 182% of boiler rating, higher loads to be carried without the preheater. The B. & W. boiler has 22,914 sq ft. heating surface (rating 79,053 lb per hr. equivalent evaporation), 2999 sq ft. superheater surface, supplying steam at 275 lb. gage and 180° to 210° F. superheat, fired with an extra-long 17-retort Westinghouse underfeed stoker with side-wall tuyeres Thirteen consecutive 24-hour tests were run without preheater, and eight with, under usual operating conditions except that each day's run was kept near some chosen rating, the general results being given in Fig. 3. The gain in efficiency due to preheating varies from 5½% at 90,000 lb. per hr. E. E. (114% of rating) to 7% at 200% rating Boiler heat transmission is of course higher with the hotter gases, and the nearly horizontal efficiency line with preheated air is due to the better transmission in the preheater with the higher temperatures and velocities at high load, and to decrease in combustible in ash The boiler-exit gas temperatures, taken before the damper, are *lower* with preheated air, due to increased heat transfer in the boiler with the higher *mean* gas temperatures which accompany high furnace temperatures and low excess air. The gain in CO_2, ranging from 0 7 to 1 4%, results from better combustion conditions, with uniform fuel bed and absence of air holes. No CO was present in the gases. Fig. 4 gives the furnace and gas temperatures, from the fuel bed, at the top of the chart, to a point after the preheater. The fuel-bed increase with preheated air is much greater than the wind-box increase (Fig. 3), due to the reduction in excess air The draft loss through the boiler was, for 114% rating, reduced from 0.31 to 0 24 in. by preheated air, and for 200% rating from 0 94 to 0 67 in., partly offsetting the reduction in stack draft with colder exit gases The fan power was 5 kw -hr. per ton, or less than 0 4% of the coal The weaving of the vertical plates with pressure and temperature variations, and gas scouring, prevented soot deposits. The fuel ignited more readily, burned uniformly throughout the bed, the clinker was hard and easily ground out, and it is believed that the stoker equipment could stand even higher temperatures than those used. The equipment was placed without additional space, and weighed less than corresponding water economizer material, which would have required induced draft for the gases and special pumps for the water. The transmission in the air heater ranged from 2.7 to 3.7 *BTU* per sq. ft. per hr. per ° F. difference, although there was no apparent relationship between this figure and the load on the heater, or the mean temperature difference.
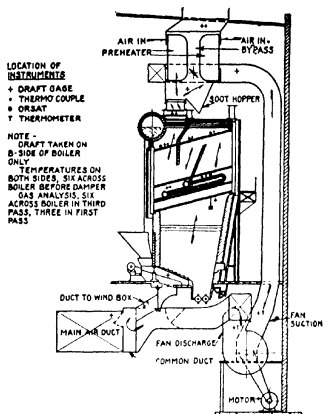
1. BOILER AND PREHEATER
SYSTEM, COLFAX STATION
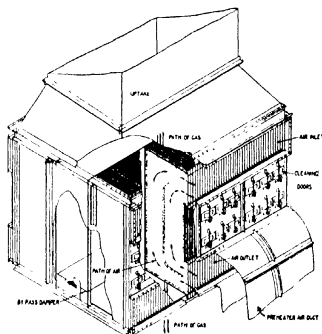
2. DETAIL OF C E C PREHEATER
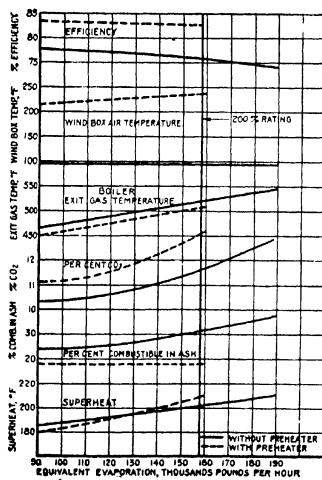
3. COMPARATIVE PERFORMANCE
WITH AND WITHOUT PREHEAT
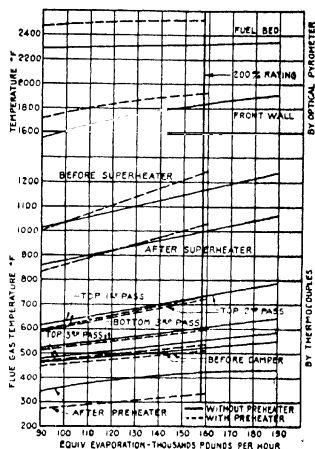
4. FURNACE AND GAS TEMPERA-
TURES WITH AND WITHOUT
PREHEAT.—A.S.M.E.

The Central Electric Supply Co. of London has installed a plant, Fig. A, in which flue gases pass first through a water economizer and then through an *Usco air preheater.* The boiler heating surface is 8619 sq. ft., superheater surface 3190 sq ft., economizer 4620 sq. ft., air heater 9020 sq. ft. When operating at 60,000 lb. per hr., the guaranteed net efficiency, based on the high heating value of the coal, 10,800 *BTU* per lb., and deducting power for stokers and for forced- and induced-draft fans, is 85%, or 86% not considering the power consumption of the unit.

Power Plant Engineering gives Fig. C, showing the average rate of heat transmission in cast iron or steel heaters, as a function of the air velocity. It does not apply to any particular condition or style of heater, but gives a general idea of the rate.

Alfred Cotton gives the following heat transmissions for air heaters consisting of 264 3-in. tubes used in connection with refuse destructors, the gas flow being through the tubes and the air flow at right angles to them.

Lb. Gas per Hr. per Sq. Ft. of Cross-sectional Area of Passages	BTU per Sq Ft per Hr per ° F Mean Temperature Difference Between Air and Gas, at Mean Temperature Difference of		
	100°	200°	300°
1000	1.6	1.7	1 8
2000	1 9	2.3	2 7
3000	2 2	2.9	3 7
4000	2 5	3 5	4 6

Carl Fred Holmboe reports tests as follows on an air heater of 1720 sq. ft. heating surface, in which the hot flue gases flowed along a duct and the air, in pipes of 3 94 in diameter, 0 39 m. thickness, passed back and forth across the duct, at right angles to the gas flow, and with the cold air entering at the colder end of the gas duct, as follows ·

Gas in, ° F ...	342	342
Gas out, ° F	293	291
Air in, ° F.	37	37
Air out, ° F..	149	117
Lb. gas per hr. ..	...95,000	99,000
$k = BTU$ per sq. ft. per hr per ° F. mean temp. dif. between air and gas, observed	2 58	2.89
Gas velocity, ft. per sec	18 0	18 4
$k_g = BTU$ per sq ft. per hr. per ° F. mean temp. dif. between gas and metal, calculated*	4 61	4 72
Air velocity, ft. per sec..........	22 5	37 4
$k_a = BTU$ per sq. ft. per hr. per ° F. mean temp. dif. between metal and air, calculated*	5 34	7 8
k, calculated†	2 48	2.93
Error in calculated k.................. ..	−4%	+ 1.5%

*Calculated from formula developed by author from experiments on transmission from steam, k_a or $k_g = 0.41 + 0.45 \ v^{0.77}$ (p. 521).

$$\dagger \frac{1}{k} = \frac{1}{k_a} + \frac{1}{k_g} \quad \text{(neglecting metallic resistance).}$$
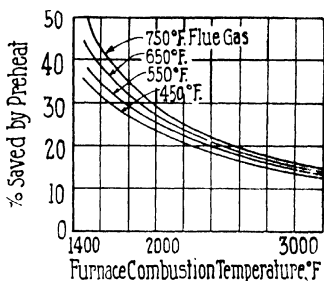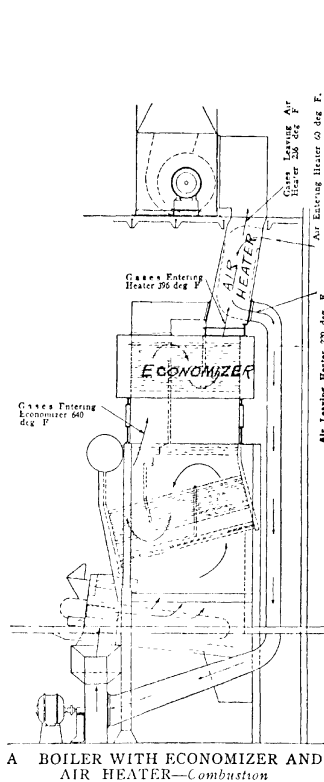
B   SAVING BY PREHEATING AIR
—*Gumz.*
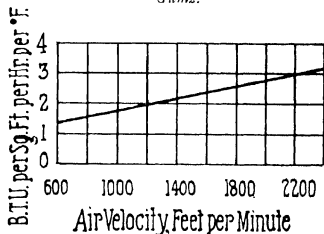
C   HEAT TRANSFER IN AIR
HEATERS —*Power Plant Engg.*

A   BOILER WITH ECONOMIZER AND
AIR HEATER—*Combustion*
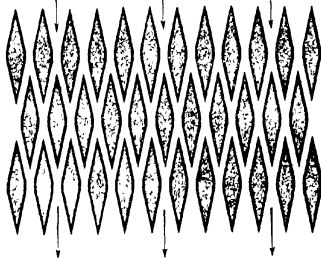
D. RHOMBUS AIR HEATER—
Z. d. V. d. Ingr.

Margolis gives the following results of tests on air heaters in which
the individual steam-carrying elements were prisms with rhombus or
diamond-shaped cross sections, with air outside flowing at right angles to
their axes, see Figure D. In the heater with 3 rows of 11 elements, the
total cross-section was 47 in. perpendicular to the air flow and 29 in.
parallel to it, the depth of the elements being 94 in.,

$$k = 0.91 \ v^{0.65}$$
$$t = 72.5 \ z/v^{0.35}$$
$$h = .0000705 \ (5 + 6 \ z) \ v^{1.4}$$
$$kt/h = \frac{935{,}000}{(5 + 6 \ z) \ v^{1.1}}$$

$k = BTU$ transferred per sq. ft. heating surface per hr. per ° F. difference steam to air; $t =$ temperature rise of the air, ° F.; $h =$ draft loss of the air, in. water; $z =$ number of rows of elements; $v =$ air velocity, ft. per sec.

The fourth equation shows that for this type of heater the performance (kt/h) is little influenced by the air velocity.

In the following, results on rhombus and tube heaters are expressed as functions of the draft loss. In spite of the increased resistance of the small tubes, the performance (kt/h) increases with reduction in tube diameter. A temperature rise of about 77° F. can be secured with 0.114 in. draft loss with either 3-row rhombus or 2 26-in. I. D. 59-in. long tubes, but k and kt/h will be 50% greater with the rhombus heaters.

	k	t	kt/h
2-row rhombus	$19.8 \ h^{0.45}$	$26.9/h^{0.25}$	$530/h^{0.8}$
3-row rhombus	$17.4 \ h^{0.45}$	$44.1/h^{0.25}$	$770/h^{0.8}$
4-row rhombus	$15.6 \ h^{0.45}$	$61.7/h^{0.25}$	$960/h^{0.8}$
2.26-in. tubes, 59 in. long	$10.0 \ h^{0.40}$	$61.4/h^{0.10}$	$614/h^{0.7}$
4.69 " 39 " "			$176/h^{0.7}$
3.71 " " "			$234/h^{0.7}$
3.25 " " "			$273/h^{0.7}$
2.75 " " "			$345/h^{0.7}$
2.26 " " "			$444/h^{0.7}$
1.81 " " "			$575/h^{0.7}$
1.32 " " "			$820/h^{0.7}$
0.85 " " "			$1360/h^{0.7}$

The accompanying Fig. E, by *George E Tansley*, gives the results of tests on an air heater containing 32 cast-iron tubes 3⅞ in bore, ⅜ in. thick, in which the cold air entered at the bottom and passed through all the tubes in parallel. In the runs indicated spirals or cores were inserted inside the air tubes, and in those marked "circulating," the air passed down 16 tubes, then up 16 and out. Runs were also made with thin solid-drawn steel tubes 4¼ in. bore and 0.175 in thick.

E. TRANSMISSION IN AIR HEATER
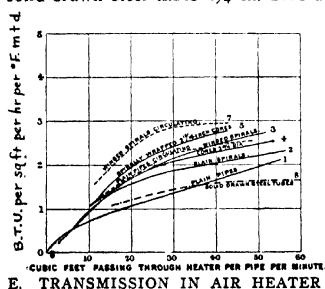
Tests by the Hammersmith Borough Council on an Usco plate air heater, 4 ft. 7 in. wide, 4 ft. 4 in. deep, 8 ft. high, with 19 air passages and 20 gas passages, each about 1¼ in. wide, 1102 sq. ft. heating surface, showed transmissions of 6.04 to 6.95 BTU per sq ft. per hr. per ° F. mean difference, average temperatures being, gas in 477°, gas out 297°, air in 74°, air out 220°. Another showed a transmission of 4.12, gas in 658°, gas out 478°, air in 51°, air out 228°.

A heater built of No. 00 gage

sheet iron, 0.3437 in. thick, consisting of 4 units in parallel, 8 ft. long, 9 ft. high, 2 ft. 6 in. wide, with 11,000 sq. ft. heating surface, handling 100,000 lb. gas per hr., showed a transmission of 1.94, temperatures being, gas in 600°, gas out 400°, air in 60°, air out 460°.

HEAT INSULATION

Furnace Walls.—Commonly there is 4% heat lost through the furnace walls. An air space has sometimes been used. The *Bureau of Mines* points out that so far as the loss of heat is concerned, a solid wall of any ordinary material is preferable to a hollow wall of the same total thickness, especially if the air space in the hollow wall is near the furnace side. The air in the air space is a poor conductor, but the heat passes through it rapidly by radiation. When heat at low temperature is to be insulated, use an air space. When heat at high temperature is to be insulated, as in a furnace, use solids of poor conductivity. Where walls are built in two parts, to prevent cracks from expansion of brickwork on the furnace side, fill the space with solid loose material. Brick or sand offers a higher resistance than air. The heat loss will be reduced 50%.

The *Bureau of Mines* at St. Louis enclosed a boiler setting entirely in an airtight iron casing. The purpose was to determine:

1. Whether air spaces in the side walls reduced the radiation losses, and therefore increased the efficiency.

2. Whether, by preventing air leakage, the heat loss in the chimney gases was reduced and the efficiency raised.

Nothing was gained in efficiency. What was gained by the air-tight setting was perhaps lost by increased radiation. The double fire door exposed too much iron surface directly to the fire, and thus increased the radiation from the furnace front. The temperature of the sheet-iron casing on the sides of the boiler often rose above the boiling point of water, indicating that too much heat passed through the air spaces in the side wall

According to *E. H. Peabody*, 85% magnesia, while entirely satisfactory for lagging, is not suitable for insulating furnace walls, but non-conductors using diatomaceous earth as a basis are light, have good insulating value, and stand temperatures up to 2000° F. The natural earth has a stratified structure, so that it is necessary to crush and calcine it, and mould with a binder. *H. T. Matthew* says that the heat loss through ordinary furnace walls averages 4%, although it may be as little as 3% with large boilers at high ratings, or as much as 15% with small boilers at very low ratings. $\frac{7}{10}$ of this can be saved by proper insulation, and insulating brick are available that show no shrinkage under a pressure of 40 lb. per sq. in. at 1900° F., and but slight shrinkage at 2000° F. Where the inside furnace temperature is 2400° F., good insulation can be installed as close as 9 in. to the inside face of the fire-brick wall, and special refractory brick can be used in contact with gases at points of higher temperature. The *Quigley Furnace Specialties Co.* gives the charts in Fig. 1 for heat loss with various types of walls, showing the saving by insulating. The fire-side is at the left in the sketches, while the charts show the heat loss as a function of the furnace temperature, calculated by the following formula based on average temperature of 1000° F.

$$BTU \text{ loss per sq. ft. per hr.} = \frac{T}{(F/7.9) + (R/7.2) + (I/0.84)}$$

where T is temp. dif. between furnace and room, and F, R and I are thicknesses of fire brick, red brick and insulation, in inches.
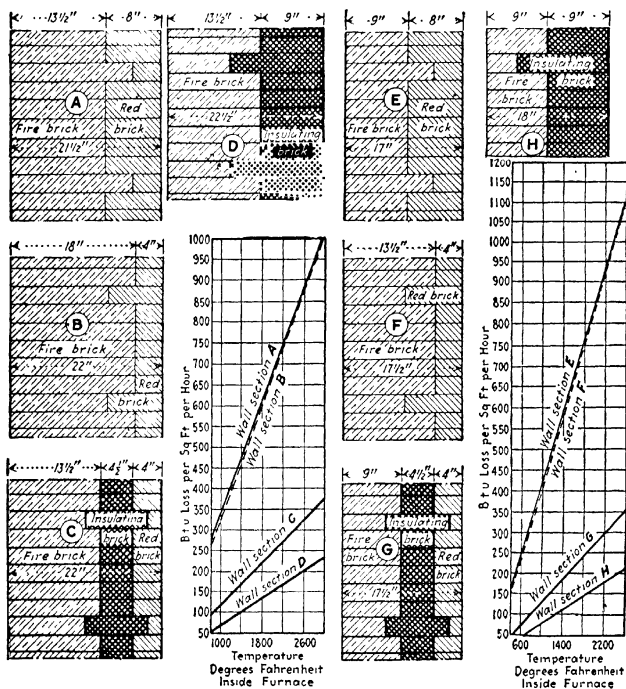
1. HEAT LOSS THROUGH VARIOUS FURNACE WALLS.—*Power*

The *Celite Products Co* gives the heat losses shown in Fig. 2, for a solid wall as illustrated and one of the same thickness with Sil-o-cel interlining. With 2500° F. furnace temperature, the values are 800 *BTU* per sq. ft. per hr. for the solid wall and 280 for the insulated For 1000 sq. ft. of wall, the 520,000 *BTU* saved per hr represents 43 lb. coal, 4.26 gal. oil or 867 cu. ft. gas. Fig 3 shows the method of tying the brick walls together with ½-in. wire mesh or expanded metal lath every 5 or 6 courses, or with 9-in. fire-brick headers, staggered, and spaced 18 in. longitudinally. Fig. 4 gives the general construction with a return tubular boiler
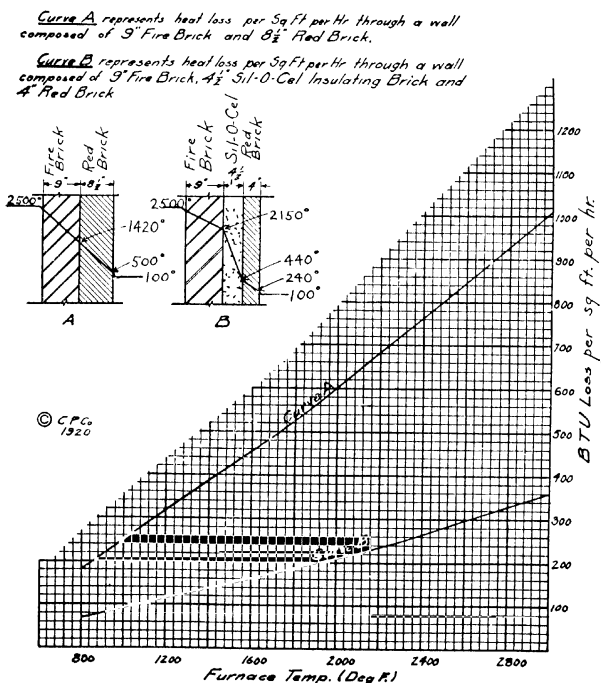
2. **HEAT LOSS FROM WALLS WITH AND WITHOUT SIL-O-CEL LINING**

FIG. 7. CONDUCTIVITY OF
REFRACTORIES
—Celite Products Co.

FIG. 6 TEMPERATURE GRADIENT
THROUGH FURNACE WALLS

FIG. 5. HEAT FLOW THROUGH
FURNACE WALLS

The accompanying charts for heat flow and temperature gradients through furnace walls are by Celite Products Co For an example, take a vertical furnace wall consisting of 9 in fire-brick, 4½ in. Sil-o-cel and 4 in. red brick, furnace temperature 2100° F, room temperature 100° F. Assuming a temperature difference of 155° F. between the outer

surface of the red brick and the air in the room, read by
interpolation in the table in Fig. 5 the factor...... . .... $A = 1.093$
Obtain from Fig. 7 the conductivity of fire-brick, which is 10 5
at assumed mean temperature of 1600° F. Connect, with a
straight-edge, the value 10 5 on line 1 of Fig. 5 with 9 in.,
the thickness of the fire-brick, on line 2, and where the
straight-edge intersects line 3, read the factor................$B = 0 86$
Connect 1.0 (conductivity of Sil-o-cel C-22 Brick at 800° F.) on
line 1 with 4½ in. on line 2, and read on line 3 factor..... $C = 4 53$
Connect 6.0 (conductivity of red brick at 350° F.) on line 1 with
4 in on line 2, and read on line 3 factor ...   . $D = 0 655$
$$\overline{7.138}$$

Connect 7.138 on line 3 with 2000° F. (temperature difference
between furnace and room) on line 4, and read on line 5
the *heat flow* $= 280 \ BTU$ per sq ft. per hr.
To determine temperature gradients, select first from table in Fig. 6 the
factor 1 829 corresponding to 155° F., difference between red brick
surface and air. Connect 1 829 on line 3 in Fig 6 with the heat flow
280 on line 5, and read on
line 4..................... 156° temp. drop at inner fire-brick surface.
Connect 9-in. fire-brick thick-
ness on line 2, Fig 6, with
10.5 conductivity on line 1,
read on line 4   . .. 241° temp drop through fire-brick
Connect 4½ in. Sil-o-cel thick-
ness on line 2 with 1 0 con-
ductivity on line 1, read on
line 4..... . ... .1260° temp drop through Sil-o-cel
Connect 4 in red brick thick-
ness on line 2 with 6 0
conductivity on line 1,
read on line 4............ 188° temp drop through red brick
From previous assumption..... 155° temp. drop at outer red brick surface
                              100° room temperature
$$\overline{2100°\ \text{furnace temperature}}$$

If the sum was materially different from the actual furnace tempera-
ture, the initial assumption of 155° F. would have to be modified and
both calculations repeated. From the above the various temperatures are
obtained by subtraction:

2100° furnace temperature
1944° inner surface of fire-brick
1703° outer surface of fire-brick, inner surface of Sil-o-cel
443° outer surface of Sil-o-cel, inner surface of red brick
255° outer surface of red brick
100° room air temperature.

8. TEMPERATURE GRADIENT THROUGH WALLS OF DELRAY BOILER
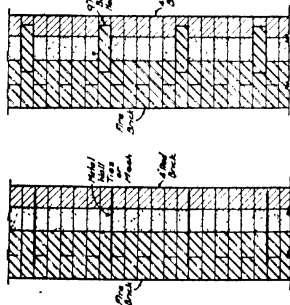
—Power

3. METHOD OF BONDING SILO-CEL WALL
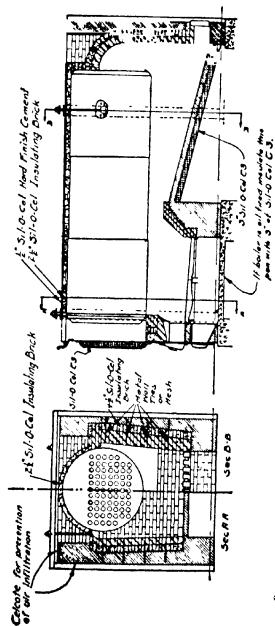
4. SILO-CEL INSTALLATION WITH RETURN TUBULAR BOILER

E. B. Ricketts, in discussing the effects of heat penetration on furnace walls, gives the values in Fig. 8, showing the temperatures by pyrometer at various distances from the inside of the solid fire-brick wall of a furnace in the Delray plant. Fig. 10 shows calculated temperatures for walls built of all brick, brick with insulating center, and brick with cooling air duct. In each of the three cases, the upper diagram represents different combinations of fire-brick, insulating brick with $\frac{1}{10}$ the conductivity of fire-brick, red brick, etc., the left-hand edge representing the outside, while the lower lines give the temperature drop from 2500° F. in the furnace. He states that there is great danger of ash erosion of the insulated walls, in which the ash-flow temperature (2300° F.) penetrates much farther than in the solid or ventilated constructions. The latter is suitable wherever it is desirable to introduce considerable secondary air, but not where all or a large part of the air is primary, as with stokers, mechanical atomizing oil burners, and certain powdered-coal systems. The general trend is said to be toward furnace chambers entirely surrounded by water and steam-cooling surfaces *C A Frankenhoff,* however, calculates the temperature in uninsulated and insulated walls to be as in Fig. 9, the ash-flow temperature penetration being only $\frac{1}{8}$ in greater for the latter, and the temperature at the back of the fire-brick only 150° F. higher He states that for the same steam production, the higher efficiency would enable an insulated furnace to operate at lower furnace temperature, with longer life of refractory.
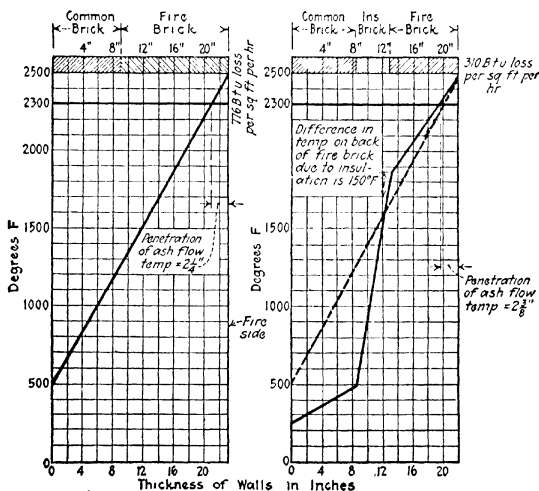
9. TEMPERATURE GRADIENT THROUGH NON-INSULATED AND INSULATED WALL—*Power*
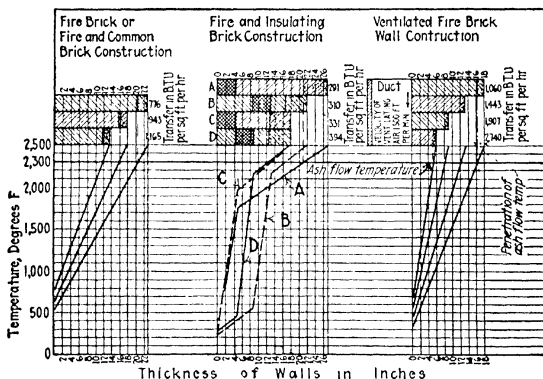
10. EFFECT OF WALL CONSTRUCTION ON PENETRATION OF DANGEROUS TEMPERATURES—*Power*

E. S. Hight describes a **boiler setting covering**, which has been adopted as standard in the plants of the Illinois Traction System, to reduce radiation and air inleakage. Wire loops, projecting about 1¼ in., are embedded between the bricks, which are painted with several coats of tar and asbestos wool, and then covered with a thick layer of asbestos paste Chicken wire mesh is placed over this, fastened to the loops, followed by a second layer of asbestos, and 10-oz. duck painted with asphalt varnish, the whole insulation being about 2 in. thick. 1·2.4 concrete is used on top of the boilers. The cost of such protection was $400 for two 500-HP. boilers in 1918, and it is estimated to give $1000 saving per year.
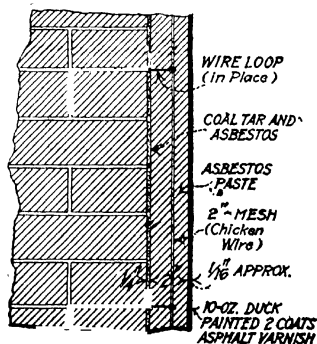
INSULATING COVERING FOR BOILER SETTING
—*Elec. World.*

Boiler and Pipe Coverings.—The heat loss from bare pipes and drums is usually assumed as 3 *BTU* per sq. ft. of surface per hr. per ° difference of temperature, but as will be noted from chart *A*, by *Glen D.*
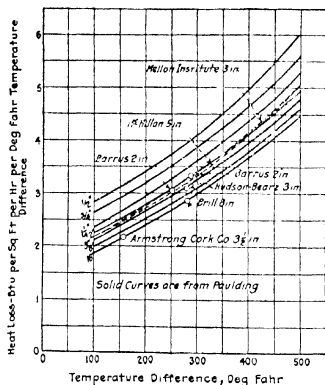
A. HEAT LOSS FROM BARE PIPE
—*Bagley.*

B HEAT LOSS FROM
3 IN PIPE WITH
85% MAGNESIA
COVERING COM
PARED WITH BARE
PIPE

Bagley, the loss per degree difference is much greater at high differences, and it increases with reduction in the size of the pipe. This chart embodies *Paulding's* formulas for various size pipes, and a number of experimental values Actual losses are also augmented by exposure to air currents As an example of the magnitude of such losses, the loss from 1000 sq. ft. of exposed pipe carrying steam at 100 lb represents over 300 tons of coal per year. By the use of good commercial coverings, 75 to 90% of this may be prevented. The average results of a series of tests on five different brands of "85% Magnesia," conducted by the *Mellon Institute* for

C COST OF 85% MAGNESIA COVERING, 1918—*A S M.E.*

the *Magnesia Association,* show heat losses from covered pipes which are insignificant as compared with those from bare pipes. See plot of losses from 3-in. pipe, in chart *B.* The saving is particularly marked at high temperature differences. The cost in 1918 is shown in chart *C,* and the economical thickness at various steam costs, for different pipe diameters, in *D.* Where steam costs are not known accurately, the thickness of covering to be used can be taken from the following tables, which are based on 13% fixed charges, evaporation of 7 lb. water per lb. coal, 1000 *BTU* above feed temperature in the steam, per lb., coal being 75%

of the cost of steam, and pipes used 24 hr. per day the year around. Where a particular pipe is cold part of the year, the price of coal should be multiplied by the number of hours pipe is in service per year, and divided by 8760, before entering the table.

THICKNESS IN INCHES OF
'85% MAGNESIA" FOR MAXIMUM NET SAVING

Size Pipe	Hot Water 175° F	Steam 5 Lb	Steam 100-200 Lb	200 Lb, 150° F Super-heat	200 Lb, 300° F Super-heat
	COAL AT $2.00 PER TON				
3/4	3/4	5/8	7/8	7/8	7/8
1½	7/8	3/4	1	1¼	2
3	1 1/32	1 1/32	1 1/32	1½	2
6	1¼	1¼	1½	2	2
12	1¼	1¼	2	2	3
24	1½	1½	2	3	3
Flat	7/8	1½	2	3	3½
	COAL AT $4.00 PER TON				
3/4	3/4	5/8	7/8	1½	2
1½	3/4	3/4	1¼	2	2
3	1 1/32	1 1/32	2	2	3
6	1¼	1¼	3	3	3
12	1½	1½	3	3	4
24	1½	1½	3	4	4
Flat	2	2	3	4	4½
	COAL AT $6.00 PER TON				
3/4	3/4	3/4	1½	2	2
1½	3/4	3/4	1½	2	3
3	1 1/32	1¼	2	3	3
6	1¼	2	2	3	4
12	1½	2	3	4	4
24	2	3	3	4	5
Flat	2½	3	4	5	5½
	COAL AT $8.00 PER TON				
3/4	3/4	1½	1½	2	3
1½	3/4	1½	2	3	3
3	1½	2	3	3	4
6	1½	2	3	4	4
12	2	3	3	4	5
24	2	3	4	5	6
Flat	2½	3½	4½	5½	6½

The following results of tests on different commercial pipe coverings are by *Paulding*:

Covering	Diam. of Pipe, in.	Thickness of Covering	Steam Temp., F	Air Temp., F	BTU loss per sq. ft. of pipe per hr.	Do., per ° temp. difference
Hair felt	2	.96	302.8	71.4	89.6	0.387
Hair felt	8	.82	348.3	69.0	117.9	0.422
Mineral Wool	8	1.30	344.1	58.3	81.3	0.284
Asbestos sponge felted	2	1.125	364.8	60.7	145.0	0.477
Asbestos sponge felted	10	1.375	364.8	62.8	85.0	0.248
Magnesia	4	1.12	388.0	72.0	147.0	0.465
Magnesia	8	1.25	344.1	66.3	106.6	0.384
Magnesia	10	1.19	365.2	66.0	103.0	0.347
Asbestos air cell	4	1.12	388.0	72.0	166.0	0.525

Steam at 20 cents per
1,000,000 BTU

Steam at 40 cents per
1,000,000 BTU

Steam at 60 cents per
1,000,000 BTU

Steam at 80 cents per
1,000,000 BTU
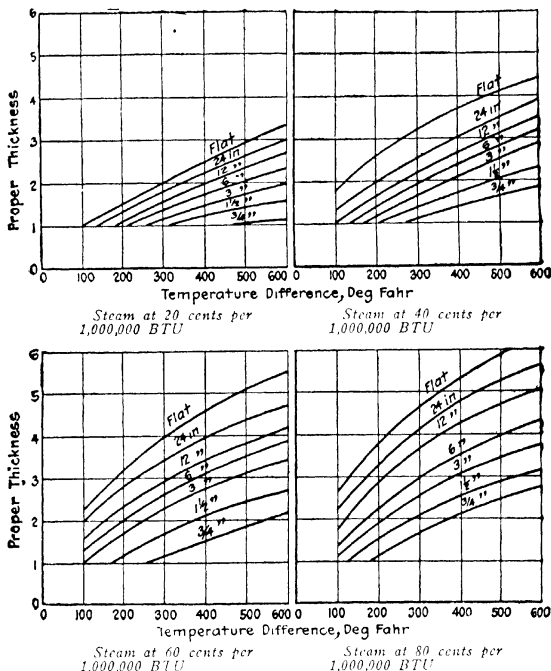
D. THICKNESS, IN INCHES, OF 85% MAGNESIA FOR MAXIMUM NET SAVING

R. H. Heilman reports investigations on losses from bare pipes, similar to those shown in Chart A, in which the results from 500° up to 800° F. differences were practically straight-line extensions of the curves at 500°. He also states that an air space of over 0 25 in. between the hot metal and its covering is of little value as an insulator on flat surfaces at high temperatures, and that it would afford very little protection to the covering. Coverings should be kept as close as possible to cylindrical surfaces, as even 0.1 in. air space actually increases the overall loss He gives the following formulas* for heat loss from insulated pipes:

*The formulas are most readily applied by inserting the numerical values of t_1, t_3, C, D and d, and solving the resulting quadratic in h. The general solution, however, is

$$h = [- b + \sqrt{(b^2 - 4\ ac)}]/2a, \text{ wherein}$$
$$a = 0.5\ D\ log_e\ (D/d)$$
$$b = - C[t_1 - t_3 - 272.5] + [282\ D\ log_e\ (D/d)]/D^{0.19}$$
$$c = - 564\ C(t_1 - t_3)/D^{0.19}$$

$$h = \frac{C \; (t_1 - t_d - t_a)}{0.5 \; D \; log_e \; (D/d)}, \text{ wherein}$$

$h = BTU$ loss per hr. per sq. ft of outer canvas surface
$C =$ mean absolute conductivity of the insulation, BTU per sq. ft. per hr. per ° F., for 1 in. thick.
$t_1 =$ pipe temperature, ° F
$t_d =$ room temperature, ° F.
$D =$ diameter of outer surface of insulation, in.
$d =$ diameter of inner surface of insulation, in
$log_e \; (D/d) = 2.3 \; log_{10} \; (D/d)$
$t_d =$ temperature difference between canvas surface and room, ° F.

$$= \frac{272.5 \; h}{h + (564/D^{0.19})}$$

The temperature drop from saturated steam to outer pipe surface is negligible (for superheated steam it may reach 10° F.). The formula assumes the inner temperature of the insulation to be the same as that of the pipe, but takes account of the conditions at the canvas surface as shown by tests on coverings of 3 to 17 in. outside diameter. For a covering 2 in. thick, $C = 0.56$, placed on a pipe of $4\frac{1}{2}$ in outside diameter, maintained at 400° F. in a room at 70° F., it gives $h = 60.4 \; BTU$ per hr. per sq.
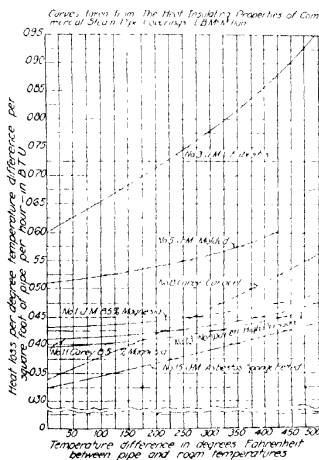
E. LOSS FROM 5-IN. PIPES WITH DIFFERENT COVERINGS
—Ill. Exp. Sta.
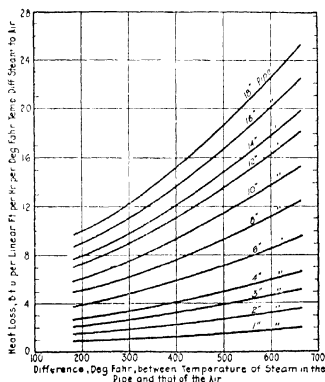
F. HEAT LOSS FROM BARE PIPES
—Heilman.

ft. canvas surface, or 114 per sq. ft. *pipe* surface, and $t_d = 37.6°$ F., so that the outer surface of the covering is at $70 + 37.6 = 107\,6°$ F.

W. A. Carter and *E. T. Cope* describe a method used for the design of covering for pipes carrying steam up to 800° F. On account of the weakening effect of temperatures over 500° F. on the mechanical strength of 85% magnesia, it was found desirable to use a protective layer between the pipe and the magnesia, of such a thickness as to limit the temperature of the magnesia to 500° F. The relations used, based on work by *Heilman* and by *H. S. Carslaw*, were:

Heat loss =

h_1 = Heat loss from canvas cover =

h_3 = Heat conducted through outer layer =

h_4 = Heat conducted through protective layer.

$$h_1 = \frac{147\,6D^{0\,81}(t_c - t_a)}{272\,5 - (t_c - t_a)}, \quad h_3 = \frac{0\,524K_a(t_1 - t_c)}{log_e(r_c/r_1)}, \quad h_4 = \frac{0\,524K_b(t_p - t_1)}{log_e(r_1/r_p)},$$

wherein h_1, h_3 and h_4 are all in BTU per hr. per linear ft. of pipe

K_a and K_b are the mean absolute thermal conductivities of the two parts of the covering, in BTU per sq. ft. per hr. per ° F temperature difference between the hot and cold surfaces, for 1 in. thickness. They are not constants, but change with the mean temperature of the materials

t_c = temp. of canvas surface of pipe covering, ° F.

t_a = temp. of surrounding air, ° F.

t_1 = temp. of outside layer of protective material and inside surface of outer layer, ° F., taken as 500°

t_p = temp. of inside surface of inner layer or of the steam, ° F.

D = diam of canvas surface, in.

r_c, r_1 and r_p = radii corresponding to t_c, t_1 and t_p, in.

log_e (r_c/r_1) = 2.3 log_{10} (r_c/r_1)

The authors give a graphical method for the solution of these equations, and also of the slightly simpler case when only one layer is necessary. For a given value of D, h_1 is calculated for a range of values of t_c, and plotted against t_c, while h_3 is also plotted against t_c, using a separate curve for each assumed value of r_1. The intersections of h_1 with the h_3's are plotted in a second chart against r_1, and h_4 calculated and also plotted against r_1. The intersection gives the value of $h_1 = h_3 = h_4$ for the given D, and also the proper r_1. The process is repeated for other values of D.

A typical proportion is $1\frac{3}{16}$-in. inner layer and $2\frac{13}{16}$-in. outer layer, for a total thickness of 4 in. on a 6-in. pipe with no part of the outer layer over 500° F. From the results of such investigations, and from Fig. F, by *Heilman*, giving heat loss from bare pipe, it is possible to plot charts of BTU saving for various thicknesses of covering, as in Fig. G, also gross monetary saving based on say 35 cents per million BTU in the steam, and the net monetary saving after deducting fixed charges on the installation and its maintenance.

The investigations showed that for pipes with a single layer of covering, and carrying steam at 500° F., the first quarter inch of covering was of more value in saving heat than any additional inch thickness of the same material, also, that fairly wide variation in thickness causes little difference in net monetary saving.

G. METHOD OF PLOTTING HEAT
    SAVINGS FROM INSULATION
              —Carter and Cope.
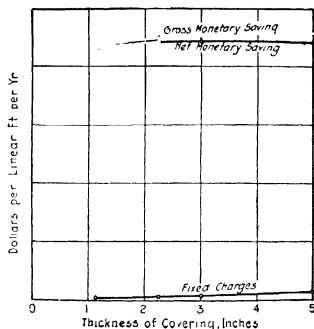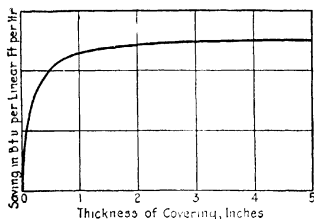
85% *Magnesia*, as defined by the Association, is an inorganic, inert
mineral composition, composed of 85% of commercially-pure carbonate
of magnesia ($4MgCO_3$ MgO_2H_2 $5H_2O$), with which is incorporated suffi-
cient asbestos mineral fiber to act as a binder, giving the necessary struc-
tural strength. The material contains myriads of microscopic crystalline
cells, each holding a small particle of dead air of high insulating value. It
is furnished in the form of half sections for pipes up to 10 in. in diameter,
segments for larger-size pipes and curved surfaces, flat blocks for boilers
and other surfaces, and plastic or fibrous powder for irregular surfaces,
filling of joints, etc.

Edward R. Weidlein describes tests made by the *Mellon Institute* on
two boilers of a total HP. of 140, and total exposed surfaces 675 sq. ft.,
with and without insulation consisting of 2 in 85% magnesia Blocks and
Plastic. Without, the equivalent evaporation was 6.35 lb water per lb.
coal; with the magnesia covering it was 7.55, and 1500 lb more was
evaporated in a day with 1488 lb less coal. The actual saving for the
same rate of driving was 15% of the coal, or 1700 lb. per day, while the
calculated saving, based on the laboratory experiments referred to, was
1400 to 1500 lb coal per day.

The Association specifications require that single-thickness pipe cover-
ing be finished with canvas jacket pasted on, and black japanned bands
on 18-in. centers. With double thickness, the joints are to be broken,
each layer secured by No. 18 annealed-iron wire, cracks filled with Plastic,
and covered with heavy sheathing-paper and 8-oz. canvas jacket sewed
on, three stitches to the inch. Flanges are to be covered with Blocks and
Plastic, or all Plastic, on ½-in.-mesh iron-wire netting, removable, and
with covering on pipe beveled to allow removal of bolts from flanges
when necessary. Exhaust piping is to be covered with sectional covering,
jacket and bands; exhaust mains with Plastic, or Block and Plastic, 1½
in. thick, with coat of hard-finish cement. Exposed tops of boilers or
drums are to be covered with Blocks, finished with ½ in. of Plastic and
coat of hard-finish cement. Covering is to be extended over top surface

of the brick setting on either side of, and in between, the boiler-tops and drums, and over top of combustion chamber. Ends of boiler-drums, both heads and rings, to be covered with Blocks and Plastic, or all Plastic, securely wired in place, with smooth finishing coat and canvas jacket, beveled around manholes. Side brick walls of boiler setting to be covered with Blocks 1½ in. wide, and Plastic to a total thickness of 2 in, all laid on expanded metal lathing or V-rib netting, securely fastened to the brickwork The bottom four feet to be protected by sheet-metal casing. On connections from boiler to main smokestack, including portions running to economizer, there shall be applied first, ½-in. mesh black iron-wire cloth with ¾-in V-iron attached, to form air-space and fastened directly to the iron, Block and Plastic being applied next. All hot and temperate air and cold-air ducts and flues, and exposed surfaces of fan-casings, tempering-coils, etc, to be covered with 1-in thick Blocks, firmly secured with No 18 galvanized-iron wire, with all block-joints pointed up with Plastic, and edges of all exposed ducts protected with light metal formed to an "L", unconcealed insulation to be finished in sheathing-paper and 8-oz. canvas jacket. Heaters, receivers, return-tanks, traps, etc, to be covered with Blocks and Plastic, thickness depending on temperature. Pipes running outdoors or exposed to extremely low temperatures to be covered with 1-in extra thickness, finished with 3-ply waterproof roofing, in place of canvas, applied with lapped joints and secured with No 16 copper wire, spaced not over 8 in. on centers.

B. N Broido gives in Tables I and II the comparative heat losses from saturated and superheated steam lines, at pressures up to 200 lb. gage, for velocities in accordance with conservative engineering practice (3000 to 5000 ft. per min. and 6000 to 10,000 ft per min) For long straight lines over 5 in in diameter, carrying steam to turbines at 300 to 500 lb., he recommends velocities of 10,000 to 12,000 ft per min. For reciprocating engines, lower velocities should be used, or enlargements of the lines immediately ahead of the engine, while the presence of a number of bends,

I. CAPACITY, RADIATION LOSS AND PRESSURE DROP OF PIPE LINES TRANSMITTING LOW PRESSURE SATURATED STEAM UP TO 200 LB GAGE

Pipe Diam. In.	Press. Abs., Lb per Sq In.	Press drop, lb per 100 ft	Velocity, Ft per Min	Wt of Steam, Lb per Hr	Million BTU Trans per Hr.	Rad Loss BTU per Hr.	Total Loss Incl. Liquid Heat	% Loss
4	115	0 54	3000	4,080	4 12	16,060	19,400	0 47
4X	165	0 79	3000	5,170	5 25	17,650	22,180	0.42
4X	215	1 03	3000	6,560	6 67	18,900	24,375	0 37
6	115	0 36	3000	9,660	9 75	23,650	28,780	0 29
6X	165	0 55	3000	10,520	10 78	26,000	32,670	0.30
6X	215	0 72	3000	13,500	13 75	27,900	36,000	0 26
8	115	0 37	3500	18,820	19 0	31,800	39,500	0.21
8X	165	0 54	3500	24,200	24 55	33 900	42,600	0 17
8X	215	0.70	3500	31,150	31 7	36,300	46,800	0.15
10	115	0 38	4000	33,850	34 15	38,410	46,750	0.14
10X	165	0.56	4000	45 200	45 88	42,280	53,130	0.12
10X	215	0 72	4000	58,200	59,30	45,320	58.460	0.10
12	115	0 50	5000	60,720	61.27	45,570	55,470	0.09
12X	165	0 72	5000	82,170	83 4	50,100	62,950	0 08
12X	215	0.93	5000	105.800	107.8	53.650	69,220	0.07

X = extra-strong pipe.

II. CAPACITY, RADIATION LOSS AND PRESSURE DROP OF PIPE LINES TRANSMITTING LOW PRESSURE SUPERHEATED STEAM UP TO 200 LB. GAGE

Press. Abs., Lb.per Sq In.	Deg. Super-heat	Press. Drop, Lb. per 100 Ft.	Velocity Ft. per Min	Wt of Steam Lb per Hr.	Million BTU Trans. per Hr.	Rad. Loss BTU per Hr.	% Loss	% by Saving Super-heat
				4-inch Pipe*				
115	100	1 24	6 000	7,020	7 46	26,400	0.34	27.7
115	150	1 18	6,000	6,575	7.15	28 800	0.40	14 9
115	200	1 12	6,000	6,225	6 92	33,200	0.48	....
165	100	1 75	6,000	8 975	9 65	26 850	0.28	33 3
165	150	1 67	6,000	8,400	9 22	31,200	0.34	19 01
165	200	1 58	6,000	7,910	8 90	35,800	0 40	4 76
215	100	2.17	6,000	11,480	12 40	28,800	0.23	37.9
215	150	2 04	6 000	10 750	11 78	33,400	0.28	24 3
215	200	1 94	6,000	10.135	11 20	38 600	0.34	8.1
				6-inch Pipe*				
115	100	0.75	6.000	16,000	17 66	37,400	0 21	27.6
115	150	0 71	6,000	15,550	16 92	42,450	0 25	13.8
115	200	0.67	6,000	14,710	16.35	49,000	0.30	....
165	100	1 04	6,000	20,280	21.80	39,400	0 18	40.0
165	150	0 99	6,000	19,000	20 85	46,000	0 22	26.7
165	200	0.94	6,000	17,900	20 15	52,650	0 26	13.3
215	100	1.29	6,000	25,950	28 00	42,400	0 15	42.35
215	150	1.22	6,000	24,320	26 85	48 900	0 18	30.8
215	200	1.16	6,000	22,950	25 90	56,700	0 22	15.4
				8-inch Pipe*				
115	100	0 71	7 000	32,410	34.5	48 600	0 14	33.3
115	150	0.67	7 000	30 390	33 1	55,100	0 17	19.05
115	200	0 64	7,000	28,710	31 85	63,700	0 20	4.76
165	100	0 99	7,000	41,470	44.45	51 380	0.12	29.4
165	150	0.94	7,000	38,810	42 6	59,770	0 14	15.62
165	200	0.89	7,000	36 580	41 08	68,610	0.17	....
215	100	1.23	7,000	53,040	57 23	55,130	0 10	33.3
215	150	1.16	7,000	49,680	54 90	63,740	0.12	20.0
215	200	1.10	7,000	46,880	52,97	73,980	0.14	6.67
				10-inch Pipe*				
115	100	0.69	8,000	58 200	61.87	60,760	0 10	28.5
115	150	0 65	8,000	54,500	59.30	68 900	0 12	14.25
115	200	0 63	8,000	51.500	57.16	79,530	0 14	....
165	100	0 95	8 000	77 500	83 10	63,670	0.08	33.3
165	150	0.91	8,000	72,500	79 60	74,580	0.09	25.0
165	200	0.86	8,000	68,400	76.80	85,620	0.10	6.65
215	100	1.19	8,000	99,100	106 9	68,800	0.06	40.0
215	150	1.13	8,000	92 800	102 5	79 530	0 08	20.0
215	200	1.07	8,000	87,600	98.9	92,320	0.09	10.0
				12-inch Pipe*				
115	100	0.87	10,000	104.200	110.8	72,070	0.07	22.3
115	150	0.82	10 000	97,800	106.4	81,600	0.08	11.12
115	200	0.78	10,000	92,500	101.8	94,340	0.09	....
165	100	1.18	10,000	140,900	151.0	76,050	0.05	37.5
165	150	1.11	10 000	131,900	144.8	88,470	0.06	25.0
165	200	1.06	10,000	124,100	139.4	101,560	0.07	12.5
215	100	1.45	10,000	180,100	194.3	81,600	0.04	42.8
215	150	1.38	10,000	168,950	186.7	94,340	0.05	28.6
215	200	1.32	10,000	159,150	179.8	109,500	0.06	14.29

*Std. Pipe for 115 lb. pressure, Extra-Strong for 165 and 215 lb.

fittings and valves also calls for lower velocities. Losses from superheated steam at 300 and 400 lb. gage are given in Table III. For heating, drying and process work, saturated steam must be kept down to 3000 to 6000 ft. per min., because of water hammer and drainage difficulty, while superheated steam can be carried at 12,000 to 15,000 ft in large pipes. *J. H. Lawrence* reports that his concern uses 15,000 ft per min. for large stations, and even 20,000 for lines used only in emergencies

TABLE III. PRESSURE DROP AND RADIATION LOSSES IN PIPE LINES
CARRYING HIGH-PRESSURE SUPERHEATED STEAM

Pressure Abs Lb	Deg Superheat	Pressure Drop Lb per 100 Ft	Velocity Ft per Min	Wt Steam Lb per Hr	Million BTU Trans per Hr	Rad Loss		Pressure Abs Lb	Deg Superheat	Pressure Drop	Velocity Ft per Min	Wt Steam Lb per Hr	Million BTU Trans per Hr	Rad Loss
							4-in Pipe (Extra Strong)							
315	100	2 60	6000	16450	17 92	32100		415	100	3 03	6000	21190	23 25	34750
315	150	2 46	6000	15400	17 18	37150		415	150	2 84	6000	19740	22 20	39550
315	200	2 34	6000	14470	16 50	42200		415	200	2 68	6000	18460	21 20	45250
							6 in Pipe (Extra Strong)							
315	100	1 58	6000	37300	40 60	47300		415	100	1 79	6000	47900	52 60	51350
315	150	1 48	6000	34900	38 90	54750		415	150	1 68	6000	44600	50 20	58400
315	200	1 39	6000	32700	37 40	62000		415	200	1 59	6000	41750	48 00	66900
							8 in Pipe (Extra Strong)							
315	100	1 44	7000	76000	82 80	60600		415	100	1 68	7000	97900	107 3	65750
315	150	1 36	7000	71200	79 50	70200		415	150	1 57	7000	91250	102 6	75000
315	200	1 29	7000	66900	76 40	79700		415	200	1 49	7000	85400	98 2	86000
							10 in. Pipe (Extra Strong)							
315	100	1 37	8000	142100	154 8	76800		415	100	1 57	8000	183000	205 0	83250
315	150	1 29	8000	133000	148 2	88700		415	150	1 48	8000	170400	192 0	94900
315	200	1 22	8000	125000	142 7	100900		415	200	1 4	8000	159500	183 6	108700
							12 in. Pipe (Extra Strong)							
315	100	1 65	10000	258500	282 0	91300		415	100	2 04	10000	332500	365 0	99000
315	150	1 56	10000	242000	270 0	105200		415	150	1 90	10000	309500	348 0	112700
315	200	1 47	10000	227000	259 0	119800		415	200	1 79	10000	290000	334 0	129200

HIGH TEMPERATURES AND PRESSURES

At the 1924 Symposium of the *A S M E* and *A S T.M.* on the effect of **temperature** upon the properties of metals, *L. W. Spring* stated that while a number of power plants were using total operating temperatures of 550 to 750° F., the latter figure had been and was still considered the tentative top limit for high-pressure power plant work, and that while large increases in working pressure can be taken care of by increase in metal thickness, **it is probable that increase of working temperatures will be much more slowly and cautiously made.**

H. J. French and *W. A. Tucker* have collected the information given in Fig. *A*, on the effects of temperature on the tensile strength of various steels, and state that the effect of temperature rise to about 1100° F. is to reduce tensile strength, proportional limit and the elastic modulus, and to greatly increase ductility. Certain combinations of composition and treat-
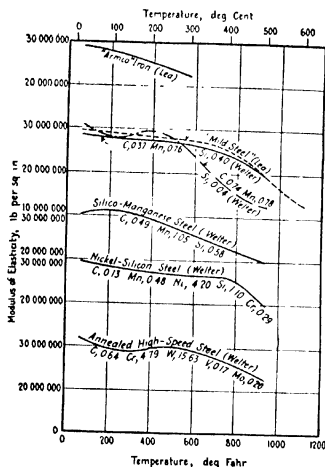
A. EFFECT OF TEMPERATURE ON STEEL IN TENSION
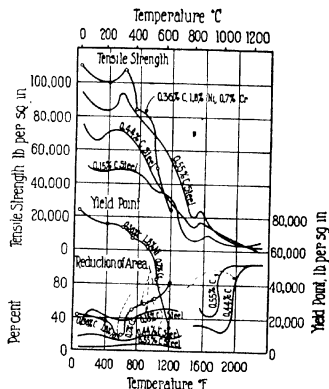
B EFFECT OF TEMPERATURE ON TENSILE PROPERTIES OF CAST STEEL.—*Power Plant Engg.*

ment are strongest at ordinary temperatures, but carbon steel and the majority of alloys show maximum tensile strength and minimum ductility in the range of 400 to 650° F. The drop in strength of steels at temperatures around 1025° F. is permanent for most practical purposes, so that it would appear improbable that commercial steels can be produced to withstand continuously fairly large loads at temperatures above about 1200° F. except when large proportions of one or more alloying elements are added to reduce the iron content to such a low value that the resulting product cannot correctly be called steel, or in special cases where extremely large proportions of special compounds are present. Fig. *B* shows the results of tests on cast carbon and nickel-chromium steels. It seems clear that irons and steels have serious limitations for high-temperature service. In the case of cast and malleable irons and semi-steels this is further substantiated by the following recommendations of one manufacturer of power-plant equipment: "Cast iron is recommended for a total temperature of 500° F. when the pressure does not exceed 25 lb. gage and for 100° F. when the gage pressure is not greater than 75 lb. Malleable iron and semi-steels are recommended for temperatures up to 500° F. when the pressure does not exceed 200 lb. gage; at higher temperatures and pressure cast or forged steels are recommended."
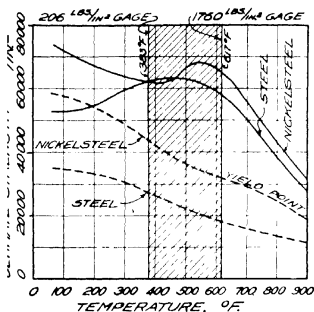
C. ULTIMATE STRENGTH AND YIELD POINT AT HIGH TEMPERATURES
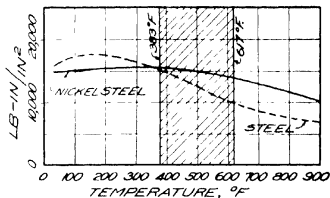
D BENDING STRENGTH AT HIGH TEMPERATURES
—*Feuerungstechnik.*

Fig C, by *F. P. Fischer* and *K. Schleip,* shows the effect of temperature on the strength and the yield point of a Siemens-Martin steel having an ultimate strength of 51,500 lb. per sq. in. at 68° F. and a 5% nickel steel of 74,500 lb. per sq. in. at 68° F. The shaded area represents temperatures corresponding to saturated steam pressures of 206 to 1760 lb. gage, although the metal in boilers will be somewhat higher in temperature than the steam with which it is in contact. Fig. D shows notch-bending tests for the same metals, made with standard bars 1.2 x 1.2 x 6.3 in., with 0.315-in. round notch, made at the middle of the bar before subjecting it to bending, the ordinates indicating the bending moment to produce rupture.

E STRESS-CREEP RELATION, 0.32% CARBON STEEL (LONG TONS OF 2240 LB)—*Prime Movers Report.*

F. C. Lea, discussing the effects of "creep" of metals at high temperatures, advances the hypothesis that at each temperature there is a particular stress below which the metal may be temporarily viscous; that is, it continues to deform under a continuously applied stress, but with time the viscous material solidifies and the rate of creep diminishes to zero. Above this stress the material continues viscous and with time will finally fracture. Fig. E, for a 0 32% carbon steel, shows the stresses below which the material would solidify with time, under stress, but above which the metal would continually creep. The stress for zero creep may be called the temperature-viscosity stress, and for the steel in question was

71,680 lb. per sq. in at 350° C. (662° F.), 40,320 at 400° C. (752° F.), 15,680 at 500° C. (932° F.), 4480 at 600° C. (1112° F.).

The results obtained show that for each of the steels tested there is at each temperature a stress which, if exceeded, will cause continuous creep. For vessels or elements of machines that are subjected to stress in one direction, this "creep" stress is the stress with which the working stress should be compared to obtain the factor of safety. For a steel containing 0.14% carbon, so long as the temperature of working is below 300° C., the factor of safety is not very different from the usual value obtained by dividing the breaking strength of the steel by the working stress. At 400° C., for a working stress of 6 tons (of 2240 lb) per sq. in., the ratio of "creep" stress to working stress is only 2 33. A vessel would withstand a pressure producing a stress of 14 tons per sq. in for a very long time without fracture. At a temperature of 500° C. the "creep" stress is reduced to 4 tons per sq. in., and thus the factor of safety, if sufficient time is allowed and the working stress maintained at 6 tons per sq. in., has become less than unity. An increase of 25% in the working stress at 400° C. (673° C. abs.) will only diminish the factor of safety from 2 33 to 1.93, whereas an increase in the temperature of 15%, reckoned on a basis of absolute temperature, while keeping the pressure constant, diminishes the factor of safety from 2 33 to less than unity. The control of temperature, when materials are subjected to temperatures of more than, say, 350° C., is thus more important than the control of pressure. For high-pressure boilers and superheaters, of mild steel, the factor of safety for temperatures of 800° F. (427° C), for a continuously applied stress of 6 tons per sq. in., is only about two, but this is clearly ample provided the temperature is not exceeded The results of the tests on materials at high temperatures, subjected to repetition stresses, show that very many millions of rapidly repeated stresses of magnitudes far greater than the creep stress can be applied without risk of fracture. These results throw important light on the possibility of materials heating after slipping, and indicate that viscosity plays an important part in the behavior of materials subject to rapid repetitions of stress at high temperatures If the fluctuations of stress are small and the stress is always in one direction the conditions approximate more and more to the statical condition, and further, if the time of application in one direction is not very small the time factor becomes of great importance, and failure may occur.

A. L Mellanby and *Wm. Kerr* state that chrome nickel steels are now available that have under high stress "creep limits" (points where the flow of steel under stress ceases) between 900° and 1000° F. They believe that 900° F. represents the steam plant limit.

Wm. F. Ryan stated in December, 1925, that boilers of practically any capacity may be obtained for **pressures** up to 1200 lb. Valves at least as large as six in. are obtainable for the same pressure. At least one turbine manufacturer is willing to quote on small, high-back-pressure turbines for initial pressures of 1000 to 1200 lb., but this company prefers to build its first machine of this kind in a larger size than could be used by the majority of industrial plants. Other turbine manufacturers are reluctant, for the present at least, to quote on any turbines for pressures higher than 600 lb. This is undoubtedly a temporary condition and one which will be changed as soon as the operating data on the one higher pressure unit so far built are available. Engines are in use operating at 400 lb. gage, and at least one engine builder is willing to supply reciprocating equipment for pressures up to 600 lb. gage.

Boiler, turbine, and valve manufacturers accept temperatures up to 750° F., but the engine builders set a limit 100° F lower. While the lubrication problem at high temperatures is a formidable one, the difficulties confronting the engine designer would appear to be less, on the whole, than those which have been overcome by the turbine designer. If a field is created for the high-pressure steam engine, there is little doubt that it will be soon adapted to higher temperatures as well as higher pressures. Central stations have demonstrated the practicability of 600 lb as a working pressure, and of 750° F. as a working temperature. They will soon demonstrate whether or not 1200 lb is equally practicable. This leaves very little development or experiment necessary for the industrial plant. Boilers, boiler auxiliaries, and valves would be the same in the industrial plant as in the central station. Turbine design should be simpler on account of the much lower range of temperatures in the high-back-pressure machine than in the condensing unit. Leakage and other handicaps to the smaller-sized unit are not so serious in this type of machine, where all of the heat not used in actual work or lost in radiation is available for use in process.

The *Superheater Co.* states that pipe lines for high pressures must be designed so that any radical changes of direction are eliminated. Globe valves are, therefore, not suitable for high pressure boilers. Only gate valves with unobstructed passages and parallel seats should be applied. It is absolutely necessary that the disk moves freely; this means that it is pressed to the seat only by the pressure of the steam. When the disk, forcibly pressed between the seats, is inserted while cold, it expands more than the casing, which is surrounded by cool air, causing undue stress on the casing. In spite of the fact that the casing may be strong enough to withstand this stress, it is very difficult, if not impossible, to withdraw the disk, even though the valve be provided with a by-pass. The standard stuffing boxes have proved to be unsuited for high pressure and temperature. Also the present packing material is not sufficient for high superheat. It is claimed that self-lubricating metal packings with asbestos between each ring are giving satisfactory results. In view of the fact that there is a considerable difference in expansion between cast steel on one side and nickel, or monel metal, on the other side, it is not advisable to use these materials for very high pressures and superheat. Valve seats of stainless or non-corroding steel with the same coefficient of expansion as cast steel are to be preferred. As it takes appreciable time to heat up a pipe line to the temperature of high pressure steam, considerable condensation occurs in the line before it is heated up. For feeding of high pressure boilers only, centrifugal pumps can be applied. By connecting the drain line into one of the stages of the pump where the pressure is lower than that in the pipe line, the condensate is forced into the pump, where it combines with the feed water going to the boiler. The only disadvantage with this arrangement is, as the pressure in the pipe changes, the drain must be connected to different stages, so the draining is not entirely automatic. The most appropriate metal for valve bodies is acid electric furnace steel. The better quality of acid electric steel is largely due to the maintenance of a reducing or non-oxidizing atmosphere within the furnace, resulting in a more nearly pure and completely degasified steel. The proper and thorough annealing of the castings is also of considerable importance.

Each of the three turbine units at the Crawford Avenue Station, Chicago, has four boilers built for a maximum delivery of 150,000 lb. per hr. at a maximum pressure of 650 lb. gage and total temperature of 750°

F., and one reheat boiler. Each of the four boilers has 16,615 sq. ft. water-heating surface, 2700 sq. ft. superheater surface and 11,054 sq. ft. economizer surface. The lower tube deck is 8 tubes high and 40 sections wide, spaced to absorb the radiant heat of the furnace and reduce slag adherence. The upper deck is 17 tubes high, 40 sections wide, with a two-pass baffle. The gases pass between nipples connecting the upper and lower parts of the downtake headers and flow downward over the wrought-steel, counter-flow economizers, which have tubes inclined slightly upward. The reheat boilers each contain 14,000 sq. ft. of reheating surface to raise the temperature of the exhaust from the high-pressure turbine element before it enters the low-pressure element, 6000 sq. ft. water-heating surface and 1700 sq. ft. superheater surface, primarily to reduce the furnace gases to 1700° en route to the reheating tubes, which contain only dry steam, and 11,054 sq. ft. economizer surface. They have steaming capacities of 96,500 lb. per hr. and reheating capacities of 480,000 lb. per hr. For the Parsons unit, both normal and reheat boilers are equipped with 10,000-sq.ft. air heaters after the economizers. If exhaust steam supply for the reheat boilers fails, emergency cooling doors can be opened. The chain grates have 423 or 444 sq. ft. effective area, and are driven by two motors each. The ashes are dumped from the rear end of the stokers to chutes which discharge beneath the water surface in pits below. Interconnected forced- and induced-draft fans are used, with 150-ft. stacks, and auxiliary fans supplying secondary air over the grates.

Stone & Webster describe the 1200-lb. boiler at the Weymouth or Edgar station of the Boston Edison Co., from which the steam at 700° F. total is delivered to a 3150-Kw. straight impulse-type 20-stage turbine exhausting at 360 lb. pressure. The exhaust from this turbine is returned to the boiler, again raised to 700° F. and delivered to the main steam header
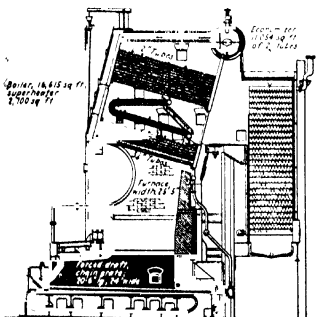
CRAWFORD AVE. NORMAL BOILER
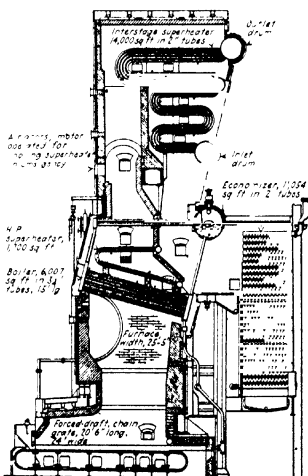
CRAWFORD AVE. REHEAT BOILER
—*Elec. World*

for use at the normal pressure of 350 lb. in the main turbines. The boiler is a modification of the conventional cross-drum type, the heating surface consisting of 2-in. tubes 15 ft. long, arranged in three passes. The tubes are separated into upper and lower banks, with a primary superheater between. Above the upper bank of tubes, is the secondary superheater or reheater. The tubes of this reheater are at right angles to the tubes in the main heating surface and are so arranged that the gas passes throughout them between the first and second passes of the boiler. The main boiler baffle between these passes is extended up into the reheater, by means of an adjustable damper, giving varying degrees of effectiveness to the reheater. Firing is by a Taylor stoker.
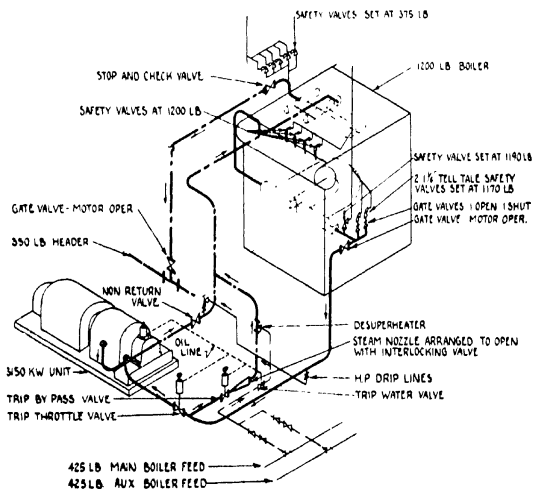
WEYMOUTH 1200-LB. BOILER—*Power*

The experimental **Emmet mercury boiler** installed at Hartford, Conn., is designed to generate mercury vapor at 35 lb. gage (812° F.), pass it through a slow-speed impulse turbine, and exhaust it at 29 in. vacuum, 414° F., to a condenser where the latent heat is used to make steam at 200 lb. pressure (388° F.). The furnace gases, from the combustion of oil, pass in order through the mercury boiler, a mercury-liquid heater, a steam superheater giving 100° superheat, and a feedwater heater. When operating the 1800-Kw. single-wheel mercury turbine (60% efficient) at 1200 Kw. load, with only 22 lb. mercury pressure, measurement of steam and oil flow showed that if the *steam* produced were used effectively, the overall fuel rate would be about 12,000 *BTU* per kw. hr., as against 18,000 to 20,000 *BTU* in large steam-driven plants. The inventor states that if the flue gases were used to heat the air for the furnace, the feedwater being

heated by bleeding the steam turbine, and with 70% efficient mercury turbines, 70 lb. mercury pressure and the most desirable steam conditions, it would be possible to operate on base load for about 10,000 *BTU* from fuel per kw. hr.
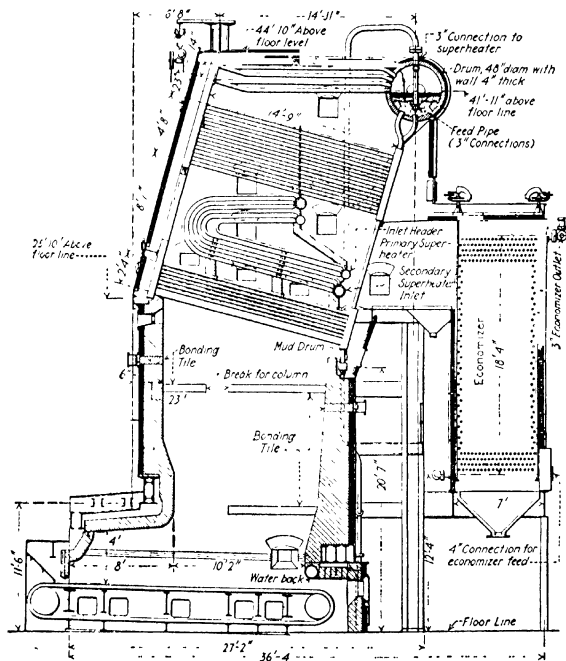
CALUMET 1200-LB. BOILER—*Power House*

The high-pressure boiler shown above was designed to supply steam at 1200 lb. to a special turbine exhausting at 300 lb. to the regular steam mains of the Calumet Station, Chicago. It contains an unbaffled lower deck of 8-high 2-in. tubes, a primary and a secondary superheater between decks, a 17-high two-pass deck and horizontal 3¼ in. circulating tubes entering a 48-in. cross drum, and is connected to a steel contraflow economizer of 9230 sq. ft., the boiler proper being 15,750 sq. ft. The primary superheater, 2120 sq. ft., is designed to deliver steam at 1200 lb. and 750° F., while the secondary superheater, 3300 sq. ft., encloses it, and is designed to receive the exhaust from the special turbine and raise it to 750° F.

Section IV—Boiler Efficiency and Boiler Testing

BOILER RATING AND CAPACITY

Those parts of the boiler shell, flues or tubes which are covered by water and exposed to hot gases or to radiation constitute the heating surface. Any surface having steam on one side and exposed to hot gases on the other is superheating surface. The *A. S. M. E. Boiler Testing Code Committee* recommends that the extent of the heating surface be measured on the side next to the gases.

A **boiler horsepower** is defined by the Committee as the equivalent evaporation of 34.5 lb. water, per hr., from and at 212° F., equivalent to 33,479 *BTU* transmitted per hr.

The original definition by the *Committee of Judges* at the *Centennial Exposition* was the evaporation of 30 lb of water per hr. from an initial feed temperature of 100° F. to steam at 70 lb gage pressure, equivalent to 33,243 *BTU* per hr.

The **factor of evaporation** is the ratio of the heat required to raise 1 lb. of feed water to boiler temperature, evaporate it and superheat it (if superheated), to that required to generate 1 lb. of steam "from and at" 212° F. It can be taken from the chart opposite, due to *W. B. Campbell*, or figured from the formula

$F = (H_1 - h_{b1})/970.4$

$H_1 =$ total heat of steam delivered, BTU per lb., above 32° F.

$h_{b1} =$ sensible heat of feed water at boiler inlet, BTU per lb. [approx. feed temp. $- 32$]

$970.4 =$ latent heat at 212° F.

For saturated or wet steam, $H_1 = H - (L \times M_s)/100$, where $H =$ total heat of dry saturated steam at boiler outlet pressure ($= h + L$ in Steam Table, p. 587), $L =$ latent heat in steam at pressure in steam main, $M_s = \%$ moisture in steam. For superheated steam, H_1 is taken from a Superheated Steam Table, or from the Condensed Table on p 590.

The $\%$ moisture in steam is determined from charts or from the following formula:

$100 \times (H - 1050.8 - 0.47\ T_s)/L$

Where T_s is ° F. of steam after expansion in calorimeter.

The actual evaporation multiplied by F gives the equivalent evaporation from and at 212° F.

The commercial or "builder's" **rating** of boilers is entirely arbitrary. It is customary to rate a stationary boiler on the basis of 10 sq. ft. of heating surface per boiler horsepower.

The **capacity** of a boiler usually designates its maximum capacity for evaporation. It is expressed ordinarily in terms of $\%$ of the builder's nominal rated horsepower.
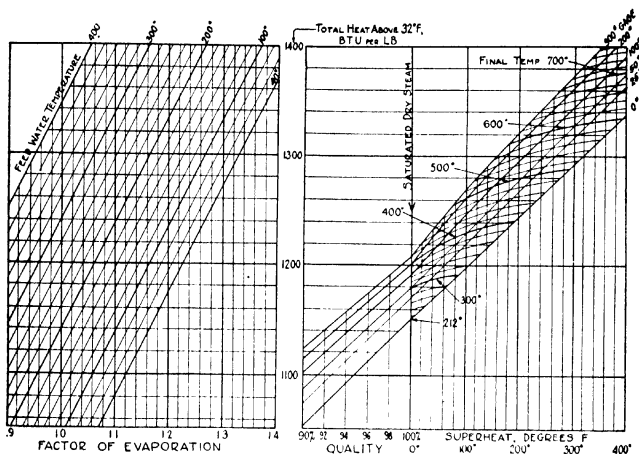
FACTOR OF EVAPORATION

Example: Enter at 100° superheat, follow vertically to 100 lb gage, left to 180°
feed water; down to Factor of Evaporation = 1.13.

HEAT BALANCE

One of the first requisites in improving boiler room practice is a record of performance. A feed water or steam flow meter* should be installed to measure the water evaporated, and the coal consumption should be determined by some method. From these quantities the evaporation per lb. of fuel can be calculated. If possible, a heat balance should be computed. Where complete data are not available, a calculation based on certain assumptions will often indicate any unusual losses.

The *1923 Power Test Code* of the *American Society of Mechanical Engineers* calls for the following items in the "Short Form" Heat Balance of a stationary boiler fired with solid fuel:

1. Heat absorbed by water and steam in boiler, superheater and economizer.
2. Heat loss due to moisture in coal.
3. Heat loss due to water from combustion of hydrogen.
4. Heat loss due to moisture in air.
5. Heat loss due to dry chimney gases.
6. Heat loss due to incomplete combustion of carbon.
7. Heat loss due to unconsumed combustible in refuse.
8. Heat loss due to unconsumed hydrogen and hydrocarbons, radiation, and unaccounted for.

* The Cochrane Meters and Metering Heaters are described in Cochrane Bulletin 668, sent on request.

PROPERTIES OF SATURATED STEAM

From Steam Tables of Marks & Davis, copyrighted. Reproduced by permission of the authors and of the publishers, Longmans, Green & Co.

Temp. Fahr. (t)	Vacuum (Referred to a 30 in barometer at 58 4° F.)	Sp Vol cu ft per lb (v or s)	Sensible Heat of the liquid above 32° F. (h or q)	Latent heat of evap. (L or r)	Entropy		
							Evap.
					Water (n or e)	$\left(\dfrac{L}{T}\text{ -or- }\dfrac{r}{T}\right)$	
32°	29.8191	3294.	0.00	1073.4	0.0000	2.1832	
35°	29.7960	2938.	3.02	1071.7	0.0062	2.1666	
40°	29.7516	2438.	8.05	1068.9	0.0162	2.1394	
45°	29.6989	2033.	13.07	1066.1	0.0262	2.1127	
50°	29.6365	1702.	18.08	1063.3	0.0361	2.0865	
55°	29.5631	1430.	23 08	1060 6	0.0459	2 0609	
60°	29.477	1208.	28.08	1057.8	0.0555	2.0358	
65°	29.376	1024.	33.07	1055.0	0.0650	2.0110	
70°	29.259	871.	38.06	1052.3	0.0745	1.9868	
75°	29.125	743.	43.05	1049.5	0.0840	1.9631	
80°	28 968	636.8	48.03	1046.7	0 0932	1.9398	
85°	28 788	545.9	53 02	1044.0	0.1023	1.9169	
90°	28.580	469 3	58.00	1041.2	0 1114	1.8944	
95°	28 341	405 0	62.99	1038 4	0.1205	1.8723	
100°	28.070	350.8	67.97	1035.6	0 1295	1 8505	
105°	27.759	304 7	72 95	1032 8	0 1383	1.8292	
110°	27.404	265.5	77.94	1030 0	0.1471	1.8082	
115°	27.005	231 9	82 92	1027.2	0 1559	1.7876	
120°	26.553	203 1	87.91	1024.4	0.1645	1.7674	
125°	26.040	178.4	92.90	1021.6	0.1730	1.7475	
130°	25.48	157.1	97.89	1018 8	0.1816	1.7279	
135°	24 83	138.7	102.88	1016 0	0.1900	1.7086	
140°	24.11	122.8	107.87	1013 1	0.1984	1.6896	
145°	23.32	109.0	112 86	1010.3	0.2067	1.6709	
150°	22.42	96.9	117.86	1007.4	0 2149	1.6525	
155°	21.43	86 4	122 86	1004 5	0.2231	1.6344	
160°	20.32	77 2	127.86	1001.6	0.2311	1.6165	
165°	19.11	69.1	132.86	998.7	0.2391	1.5989	
170°	17.77	62.0	137 87	995 8	0.2470	1.5816	
175°	16.30	55 7	142.87	992.9	0.2550	1.5645	
180°	14.67	50 15	147.88	989.9	0.2628	1.5476	
185°	12 89	45.25	152 89	986.9	0.2706	1.5310	
190°	10 93	40 91	157.91	983 9	0.2783	1.5146	
195°	8 80	37.04	162.92	980.9	0 2860	1.4984	
200°	6.47	33.60	167 94	977.8	0.2937	1.4824	
205°	3.93	30.53	172.96	974.7	0 3012	1.4666	
210°	1.16	27.80	177.99	971.6	0.3087	1.4510	
212°	0.00	26.79	180.00	970.4	0.3118	1.4444	

Temp. Fahr. (t)	Pressure lb. per. sq in gauge	Sp. Vol. cu. ft. per lb (v or s)	Heat of the liquid (h or q)	Latent heat of evap (L or r)	Entropy Water (n or e)	Entropy Evap $\left(\dfrac{L}{T}\text{or}\dfrac{r}{T}\right)$
212°	00 00	26 79	180 00	970 4	0 3118	1 4447
215°	00 90	25 35	183 0	968 4	0 3163	1 4354
220°	2 49	23.15	188 1	965 2	0 3238	1 4199
225°	4 21	21 17	193 1	962 0	0 3312	1.4052
230°	6 07	19 39	198 2	958 7	0 3384	1 3905
235°	8 09	17 78	203 2	955.4	0 3458	1 3754
240°	10 27	16 32	208 3	952.1	0 3531	1 3607
245°	12 61	15 01	213 4	948 7	0 3603	1.3465
250°	15 12	13 82	218 5	945 3	0 3675	1.3321
255°	17.83	12 74	223 5	941 9	0 3747	1 3179
260°	20.72	11 76	228 6	938 4	0 3818	1 3040
265°	23 82	10 87	233 7	934 9	0 3888	1.2903
270°	27 15	10 06	238 8	931 4	0 3959	1.2766
275°	30 70	9 32	243 9	927.9	0 4029	1 2629
280°	34 48	8 64	249 0	924 3	0 4098	1 2496
285ᵈ	38 54	8.02	254.2	920.5	0 4168	1.2363
290°	42 85	7 46	259 3	916 9	0 4235	1 2232
295°	47 43	6.94	264,4	913 2	0 4304	1 2101
300°	52 30	6 46	269 6	909 5	0 4371	1 1972
305°	57.47	6 03	274.7	905.7	0 4439	1 1844
310°	62 97	5 62	279 9	901 9	0 4507	1 1717
315°	68 79	5 26	285 0	898 0	0 4573	1 1592
320°	74 93	4 91	290 2	894 2	0 4640	1 1468
325°	81.45	4.60	295 4	890 2	0.4705	1 1346
330°	88.30	4 306	300 6	886 3	0 4771	1 1225
335°	95 6	4 035	305 8	882 3	0 4837	1 1103
340°	103 3	3.787	311.0	878 3	0 4902	1 0984
342°	106 5	3.692	313 0	876.7	0.4928	1 0937
344°	109 7	3 600	315 1	875 1	0 4954	1.0889
346°	113 0	3 511	317 2	873 4	0 4980	1 0841
348°	116 4	3 425	319 3	871.8	0.5006	1 0794
350°	119 9	3.342	321 4	870 1	0.5032	1 0748
352°	123 4	3 261	323 5	868 5	0 5058	1 0700
354°	127 0	3 182	325 6	866 8	0 5084	1 0653
356°	130 7	3.105	327 7	865 2	0 5110	1 0607
358°	134 4	3.030	329.8	863 5	0 5136	1 0560
360°	138 3	2 957	331 9	861 8	0 5162	1.0514
362°	142 2	2.887	334.0	860 2	0.5187	1 0468
364°	146.1	2 820	336 1	858 5	0.5213	1 0422
366°	150.2	2.754	338.2	856.8	0 5238	1.0377

Temp Fahr (t)	Pressure lb per sq in gauge	Sp Vol. cu ft per lb (v or s)	Heat of the liquid (h or q)	Latent heat of evap (L or r)	Entropy	
					Water (n or e)	Evap ($\frac{L}{T}$ or $\frac{r}{T}$)
368°	154 3	2 690	340 3	855 1	0 5263	1 0332
370°	158 6	2 627	342 4	853 4	0 5289	1 0286
372°	162 9	2 567	344 5	851 7	0 5314	1 0240
374°	167 2	2 508	346 6	850 0	0.5340	1 0194
376°	171 7	2 450	348 7	848 3	0 5364	1 0150
378°	176 2	2 394	350 8	846 5	0 5389	1.0105
380°	180 9	2 340	352 9	844 8	0 5413	1 0060
382°	185 6	2 287	355 0	843 1	0 5439	1 0015
384°	190 4	2 236	357 2	841 3	0 5464	0 9971
386°	195 3	2 186	359 3	839 6	0 5488	0 9928
388°	200 4	2 137	361 4	837 8	0 5513	0 9884
390°	205 5	2 089	363 5	836 1	0 5539	0 9840
392°	210 7	2 013	365 6	834 3	0 5565	0 9796
394°	216 0	1 999	367 7	832 5	0 5590	0 9752
396°	221 4	1 955	369 9	830 7	0 5615	0 9708
398°	226 8	1 913	372 0	829 0	0 5639	0 9665
400°	232 4	1 872	371.1	827 2	0 5663	0 9623
410°	261 6	1 679	384 7	818 2	0 5786	0 9409
420°	293 7	1 510	395 4	809 0	0 5908	0 9198
430°	328 3	1 361	406 2	799 6	0 6029	0 8990
440°	366 1	1 229	417	790 1	0 6149	0 8785
450°	406	1 11	428	780	0 627	0 858
460°	450	1 00	439	770	0 639	0 837
470°	498	0 90	451	759	0 651	0.816
480°	550	0 81	462	748	0 662	0 796
490°	607	0 73	473	737	0 674	0 776
500°	669	0 66	484	725	0 686	0 755

CONDENSED TABLE OF TOTAL HEAT OF SATURATED AND SUPERHEATED STEAM

Computed from *Marks & Davis'* Tables for temperatures below 320° F., and from the preliminary report of the *A S M E. Committee on Properties of Steam,* for higher temperatures

H_1 = Total heat of steam over 32°, BTU per lb.

Vac. (30" bar.)	Sat Steam Temp.	0°	50°	100°	150°	Superheat 200°	250°	300°	350°	400°
29	79	1094	1116	1139	1162	1185	1208	1231	1254	1277
25	134	1118	1141	1164	1187	1210	1233	1256	1279	1303
20	161	1130	1153	1176	1199	1222	1245	1268	1291	1315
15	179	1137	1161	1184	1207	1231	1254	1277	1300	1324
10	192	1143	1166	1189	.1212	1235	1259	1282	1305	1329
5	203	1147	1170	1194	1217	1240	1264	1287	1310	1334.

H_1 = Total heat of steam over 32°, BTU per lb.

Gage Pres.	Sat. Steam Temp.	0°	50°	100°	150°	Superheat 200°	250°	300°	350°	400°
0	212	1150	1174	1197	1221	1244	1268	1291	1315	1339
5	228	1155	1180	1203	1227	1251	1275	1299	1322	1346
10	240	1160	1185	1209	1233	1256	1280	1304	1328	1352
15	250	1164	1189	1213	1237	1261	1285	1309	1332	1357
20	259	1167	1192	1216	1241	1265	1289	1313	1337	1361
25	267	1169	1195	1219	1244	1268	1292	1316	1340	1365
30	274	1171	1197	1222	1247	1271	1295	1320	1343	1368
35	281	1173	1200	1225	1249	1274	1298	1322	1346	1371
40	287	1175	1202	1227	1252	1276	1300	1325	1349	1374
45	293	1177	1204	1229	1254	1278	1303	1327	1352	1376
50	298	1178	1206	1231	1256	1281	1305	1330	1354	1379
60	307	1181	1209	1234	1259	1284	1309	1334	1358	1383
70	316	1183	1212	1237	1263	1288	1312	1337	1362	1387
80	324	1185	1214	1240	1266	1291	1316	1340	1365	1390
90	331	1187	1216	1243	1268	1293	1318	1343	1368	1393
100	338	1189	1218	1245	1271	1296	1321	1346	1371	1396
120	350	1192	1221	1249	1275	1301	1325	1351	1376	1402
140	361	1194	1224	1252	1279	1305	1330	1355	1381	1406
160	371	1196	1227	1255	1282	1308	1333	1359	1385	1410
180	380	1197	1229	1258	1285	1311	1336	1363	1388	1414
200	388	1199	1231	1260	1287	1314	1340	1366	1392	1417
250	406	1201	1234	1264	1292	1320	1346	1373	1399	1425
300	422	1203	1237	1268	1297	1325	1352	1379	1405	
350	436	1203	1239	1271	1300	1319	1356	1383	1410	
400	448	1203	1241	1274	1304	1333	1360	1388	1414	
500	470	1202	1244	1278	1309	1339	1366	1394		
600	489	1201	1245	1281	1313	1343	1373	1400		
700	506	1198	1246	1283	1316	1347	1377			
800	521	1194	1247	1284	1318	1350	1380			
900	534	1190	1246	1285	1320	1352	1383			
1000	547	1185	1245	1285	1321	1354	1386			
1100	558	1180	1244	1285	1322	1356	1388			
1200	569	1175	1243	1284	1322	1357	1389			

Each of the heat balance items is computed as a number of BTU per lb. of coal as fired, or per lb. of dry coal, and is then reduced to a % of the heating value per lb., as fired or dry, the same basis being used throughout. Percentage results will be the same by either method. The following discussion and the specimen balance on page 602 are on the dry-coal basis.

1. **The Heat Absorbed by the Boiler.**—The heat absorbed per lb. of dry coal fired is equal to

$(H_1 - h_{b1}) \times$ lb. water actually evaporated per lb. dry coal fired, where H_1 = total heat of steam delivered, BTU per lb., h_{b1} = total heat, BTU per lb., in feedwater at boiler inlet.

For either superheated or saturated steam, $H_1 - h_{b1}$ also equals 970.4 × Factor of Evaporation (p. 586).

If a separate economizer is used, the heat absorbed by economizer can be figured as a separate item from the boiler and superheater.

The % of heat absorbed, i e, the overall efficiency of the boiler and furnace, equals the BTU absorbed per lb. of dry coal divided by the heating value of 1 lb. of dry coal.

2. **Moisture in the Coal.**—Water in coal must be evaporated and superheated, and escapes at the flue temperature. Heat is thus rejected to the chimney, and hence moisture in coal, in addition to being a dead weight, is an active heat waster.

This loss can be determined from the following formula:

Loss in BTU per lb. of dry coal
$= (M_c/100) \times (1089 + 0.46 \ T_6 - T_{13})$

Where M_c = % moisture in coal, dry basis, T_6 = ° F. of gases leaving boiler, T_{13} = ° F. of fuel as fired.
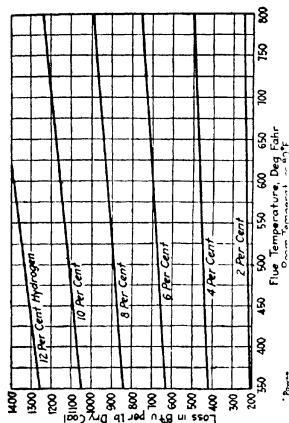
LOSS DUE TO HYDROGEN IN COAL—
H. O'Neill

LOSS DUE TO MOISTURE IN COAL—O'Neill
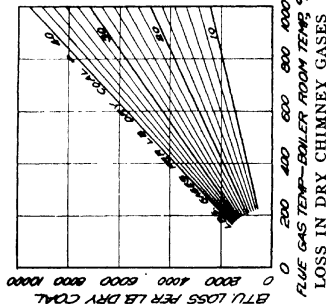
LOSS DUE TO COMBUSTIBLE IN
REFUSE
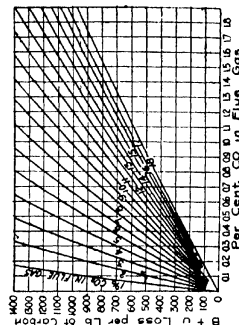
LOSS DUE TO UNCONSUMED CAR-
BON CONTAINED IN THE CO IN
THE FLUE GASES.—Power.

LOSS IN DRY CHIMNEY GASES
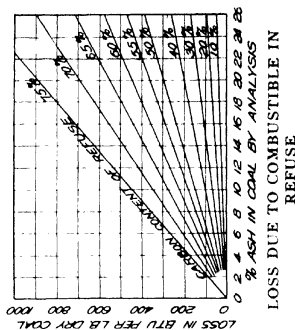
The moisture loss with small percentages of moisture increases about 1% for every 10% of free moisture The moisture in high-grade coals will average about 4%, and it does not usually pay to spend much effort to reduce it. The % loss is usually insignificant.

The *Wickes Boiler Co.* classifies moisture in coal as follows:

1. Moisture held within the pores of the coal by capillary attraction, unavoidable.
2. Moisture appearing on the surface as mined, also unavoidable
3. Due to rain and snow during transit or storage, partly avoidable.
4. Put in by fireman with hose, avoidable.

EFFECTS OF MOISTURE:

Hydrogen usually escapes more freely in presence of moisture.
Is detrimental when coal is fired in pulverized form, due to coking.
Increases liability of spontaneous combustion.
Coals high in moisture are usually high in ash.

It may sometimes be necessary to wet coal due to its fineness, in order to hasten its coking and so prevent loss due to falling through grates, or sometimes fine, dry coal packs and prevents the requisite amount of air reaching the fuel This can be somewhat prevented by wetting. The question of wetting must be decided in each individual case, but never use more water than is absolutely necessary.

3. **Hydrogen in the Coal.**—A lb. of hydrogen burned in an inclosed calorimeter in which the resulting water vapor is condensed will produce 62,000 *BTU*. Therefore, other things being equal, the richer the coal is in hydrogen, the higher its heat value. In a bomb calorimeter, the latent heat of evaporation of the water which results from the burning of the hydrogen with oxygen is credited to the coal, but in an open furnace, this heat, together with that required for superheating from boiling temperature to the flue temperature, is wasted. Therefore, to estimate the true available heat of the coal, a deduction, depending upon the percentage of hydrogen, would have to be made from the calorimeter value, giving the so-called "low value." Heat balances are, however, figured on the "high" or calorimeter value, and the difference as calculated for the particular boiler conditions enumerated as a "loss" against the heating value. The loss is of course unavoidable, although it is larger at high flue temperatures.

The hydrogen loss may be computed from the following formula:

Loss in *BTU* per lb. of dry coal

$$= (H_c/100) \times 9 \times (1089 + 0.46\ T_6 - T_{12})$$

where $H_c = \%$ hydrogen in dry coal. In items 2, 3, 4 and 5, if an economizer is installed, but no air heater, substitute $T_7 (= °\ F.$, gases leaving economizer) for T_6; if air heater is installed, substitute $T_8 (= °\ F.$ of gases leaving air heater) for T_6.

Where an ultimate analysis of the coal is not available, this item goes into the unaccounted-for losses. It is possible for several coals to show the same value in the calorimeter and yet differ as much as 3 to 4% in actual commercial value as steam producers.

4. **Moisture in the Air.**—There is a loss of heat due to the necessity of superheating the water vapor in the air from atmospheric temperature. The amount of moisture per lb. of air used can be obtained from the table following by multiplying by the relative humidity prevailing at the time of the test, which can be taken from the weather reports, or ascertained by means of a psychrometer.

WEIGHT OF WATER VAPOR IN SATURATED ATMOSPHERE
—R. C. Carpenter.

Temp. ° F.	Weight of mixture, lb. per cu. ft.			Weight of vapor per lb. of air
	Air	Vapor	Total	
0	.0863	.000079	.086379	.00092
12	.0840	.000130	.084130	.00155
22	.0821	.000202	082302	.00245
32	.0802	.000304	.080504	00379
42	.0784	.000440	078840	00561
52	.0766	.000627	.077227	.00819
62	0747	000881	.075581	01179
72	.0727	.001221	073921	01680
82	0706	001667	.072267	.02361
92	0684	002250	.070717	03289
102	0659	002997	068897	04547
112	0631	003946	.067042	06253
122	.0599	.005142	065046	08584
132	.0564	006639	.063039	.11771
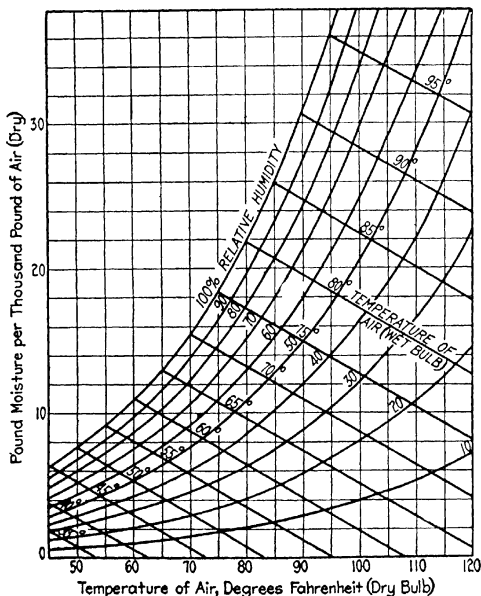
A. WEIGHT OF MOISTURE IN AIR

Absolute humidity is the amount of moisture, often expressed in grains per cu. ft., present in a given space, from which its weight per lb. of air is easily found. Relative humidity is the ratio of the moisture actually present to the moisture that would be present if the space were saturated at the given temperature. The sling type of psychrometer, which is the more satisfactory, gives the humidity by comparing the temperatures shown by two thermometers which are whirled in the air at about 200 rev. per min. The bulb of one is covered with a close-fitting piece of muslin, moistened with water, and reaches a lower temperature, corresponding to the rate of evaporation of the water, which is dependent on the humidity prevailing. The relative humidity, and the weight of the moisture per lb. of air, can be obtained from Fig. A, by *Haylett O'Neill.*

Loss in BTU per lb. dry coal.

$$= M_a \times A_1 \times 0.46(T_6 - T_4)$$

where $M_a =$ lb. moisture per lb. air, $T_6 = °$ F. gases leaving boiler, $T_4 = °$ F. of air for combustion.

$A_1 =$ lb. air supplied per lb. dry fuel, calculated from *furnace* gas analysis

$$= G_f + (9 \times H_c/100) - (100 - R)/100$$

$H_c = \%$ hydrogen in dry coal

$G_f =$ lb. **dry gas** in *furnace* per lb. dry fuel.

$$= C_b \times (11\ CO_2 + 8\ O_2 + 7\ CO + 7\ N_2)/(3\ CO_2 + 3\ CO)$$

CO_2, O_2, CO and $N_2 = \%$ in furnace gases, by volume.

$C_b =$ lb. carbon burned per lb. dry fuel.

$$= (C_c/100) - (R \times C_r/100^2)$$

$C_c = \%$ carbon in dry coal.

$C_r = \%$ combustible in refuse.

$R =$ refuse, $\%$ of dry fuel.

If it is not practicable to weigh the refuse, or if for other reasons it is preferred to calculate the value of R, it may be taken as equal to $100 \times A_a/(100 - C_r)$, where A_a is $\%$ ash in dry coal by analysis.

The loss due to moisture in air is small, and is frequently not determined.

5. Heat in Dry Chimney Gases.—The loss of heat in the chimney gases is directly proportional to the amount of air admitted to the boiler setting, and to the temperature of the gases. Even in well-cared-for settings, the inleakage amounts to 25% of the gases passing through the uptake. This loss is usually the largest, and the one in which the greatest saving can be made. It can be brought down to 15%. A large loss indicates dirty boilers, leaky baffles, defective setting or improper handling of fire or draft, the cause being easily determined by physical inspection.

The loss of heat in the flue gases, in BTU per lb. of dry coal

$$= G \times 0.24\ (T_6 - T_1)$$

$T_6 = °$ F. of gases leaving apparatus.

$T_1 = °$ F. of surrounding air.

$G =$ lb. dry gases per lb. dry fuel (see Item 4), based on appropriate gas analyses in outlet of boiler, economizer or air heater.

The *Wickes Boiler Co.* lists the following causes of heat loss in dry chimney gases:

A. Too large quantity of flue gas, due to excess air   Revealed by low CO_2. The largest of all boiler losses, nearly proportional to amount of air used.

B. **High flue-gas temperature, resulting from:**

a. Poor transfer rate, gases to metal:

1. Dirty heating surface externally, due to soot, dust, etc.
2. Low CO_2 with excess air and low *furnace* temperature.
3. Insufficient mixing of distilled and dissociated gases and air
4. Incomplete combustion in furnace, followed by secondary combustion in gas passes
5. Gases striking heating surface before combustion completed
6. Loss to stack of uncombined hydrogen, hydrocarbons, and CO
7. Stagnant gases upon any part of heating surface
8. Poor bathing of heating surface, with a short downward flow
9. Not sufficient scrubbing action and velocity of gases to wipe away gas cooled and adhering to heating surface.
10. Short gas pass of large cross section
11. Short circuiting heating surface, with a short downward flow.
12. Stratification or laning of gases through open gas passes
13. Baffles leaky, broken, or fallen out of place.
14. Ratio of combustion to furnace volume too high
15. Poor stoker application for coal to be burned.
16. Defective leaky setting, admitting excess air, cooling gases

b. Poor absorption, metal to water:

1. Dirty heating surface internally due to scale grease, mud, difficult to clean.
2. Sluggish water circulation or stagnant water.
3. Pockets of steam in gas-swept surface
4. No mud drum to hold impurities precipitated from water
5. Heavily overcrowded heating surface.
6. Poor damper control.
7. Little or no heat transferred by radiation

6. **Carbon Monoxide.**—The loss due to burning the carbon to CO instead of CO_2 may assume large proportions, but is ordinarily almost nothing. Loss in BTU per lb. of dry coal equals

$$10160 \times C_b \times CO/(CO_2 + CO)$$

CO and $CO_2 = \%$ by volume in gases at outlet of boiler, economizer or air heater.

C_b = carbon burned per lb. dry fuel. (See Item 4.)

The *Wickes Boiler Co.* lists the following factors productive of CO in the escaping gases:

1. Too thick a fire or a dirty fire.
2. Too small an air supply.
3. Draft not suited to thickness and quality of fire bed.
4. Combustion chamber too small to permit time for mixing of gases and air.
5. Furnace temperature so low that gases are not raised to ignition point on dissociation.
6. Fusion of ash on surface of fuel, forming a blanket against air admission.
7. Heavy firing at long intervals of time.
8. Lack of time for combustion to be completed before reaching boiler surface.
9. Fresh, moist coal thrown on a bed of white-hot coke.

(Smoke usually appears and hydrocarbons and hydrogen gases are usually lost as CO appears. When CO_2 exceeds 15%, CO usually appears.)

7. **Combustible in the Refuse.**—The *A. S. M. E. Code* gives for this loss, in *BTU* per lb. dry coal.

$$14600 \times (R - A_a)/100$$

where R = refuse, % of dry fuel
A_a = % ash in dry coal, by analysis

This formula is based on the assumption that no solid combustible is carried out with the gases and that $(R - A_a)$ is all carbon. If the refuse is analyzed for its % combustible, C_r, the loss is sometimes calculated as equal to $14600 \times C_r \times R/100^2$, or as $(C_r/100) \times 14600 \times A_a/(100 - C_r)$.

Under the best conditions, the loss due to combustible in refuse will be as small as 1%. In extreme conditions it may run up to 20%. An average of 77 tests at the St. Louis plant of the *Geological Survey* showed 4.9%. It ranged from 1.68 to 18.88%, and covered almost every variety of coal under fair operating conditions. *Hays* says that the average boiler furnace deposits 5% of its combustible in the refuse. *C. C. Linde* states that the loss in unburned fuel may be reduced to an amount equal to about 10 or 15% of the ash by analysis, and therefore to about 2% of the fuel as fired. *H. D. Fisher* says: "Except where the grate is too coarse and entirely unsuited for the fuel, or the coal clinkers badly, the refuse should not contain over 30% combustible." This item of loss in the heat balance should not exceed 3%.

Haylett O'Neill offers the adjoining chart showing the unavoidable heat losses in burning coals of different ash contents. The higher ash coals not only have less heat value, but a larger amount of the combustible present is carried off with the ash, as shown by the slope of the line marked "combustible in refuse."

Hays suggests a douche of water to show up coal and coke in the ash. "Give the fireman an object lesson at the ash pile when it rains. You must expect to find some coke in the ash. In the absence of a laboratory analysis to determine the combustible in the ash, weigh all of the coal and ash each day. Take a couple of shovelfuls of each barrow of ash, douche with water and carefully pick over. Weigh the unburned coal and the ash proper."
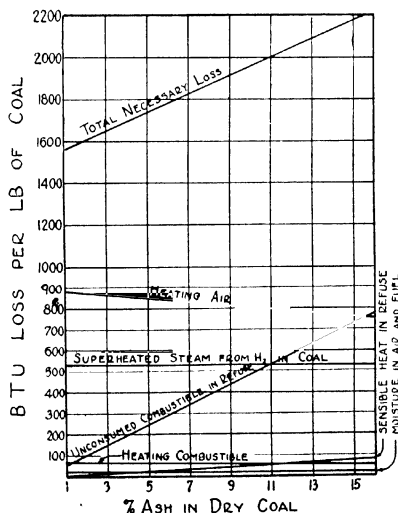
NECESSARY HEAT LOSSES BURNING COAL OF DIFFERENT ASH CONTENT.—*Power.*

The *Wickes Boiler Co.* mentions the following causes of unconsumed combustible in the refuse:

1. Coal unsuited to grate and furnace.
2. Too large openings in grate.
3. High ash content fusing at low temperature forming clinker.
4. Too high a furnace temperature, fusing ash to clinker.
5. Too frequent cleaning of fires due to clinker
6. Too frequent shaking of grates
7. Too frequent dumping of grates or dump baskets of stokers.
8. Too frequent poking, raking, hoeing, and slicing.
9. Firing green coal onto bare spots on grate
10. Carelessness in shoveling, fuel bed not kept level
11. Too high a rate of combustion for draft available
12. Poorly proportioned grate or stoker to rate of combustion, draft, and kind of coal.
13. Too small a furnace volume for rate of combustion desired
    Causes of clinker· Too thick a fire bed excessive slicing of fires, thin spots in fire, regulating draft by ashpit doors, coal burning in ashpit, preheating air, much slack in coal, no water in ashpit

E. Ogur states that the loss of sensible heat in refuse from furnace is not less than 1 5% under the most favorable conditions, and may amount to 4.5% with fuel containing 25% ash initially and with 35% combustible in the refuse (total refuse 38% of coal fired). The heat content of refuse could be determined by quenching it in a metal water barrel of known heat equivalent; however, the specific heat of refuse from most coals, at a given temperature, can be taken as $0.36 + 00015\ t$, where t is the temperature in ° F. If a pyrometer shows that the refuse is removed at 2400° F., and room temperature is 75° F., the mean specific heat for this range is $0.55\ BTU$ per lb. per ° F. rise, and if the weighed refuse is 20% of the dry coal, the loss is $0.55 \times 2325 \times 0.20 = 255\ BTU$ per lb. dry coal fired, which would be 1 7% of 14700 BTU.
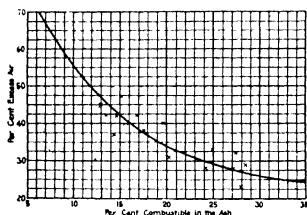
1. RELATION BETWEEN COMBUSTI-
   BLE IN ASH AND EXCESS AIR
   FOR CASE CONSIDERED
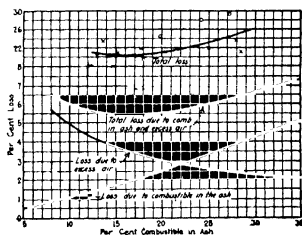
2. VARIATION IN LOSSES WITH
   COMBUSTIBLE IN REFUSE
                              —*Power.*

George E. Gaster discusses the relative importance of excess air and combustible in refuse, from an investigation of a 7000-sq.-ft. horizontal water-tube boiler, set with an underfeed stoker equipped with dump plates. Fig. 1 gives the observed relationship, for this installation using a particular coal, between excess air and combustible in ash, while Fig. 2 gives the losses due to these two items, assuming 500° temperature difference between flue and room, and pure carbon as the combustible part of the ash. The sum of these two losses is a minimum at 16% combustible in ash—an attempt to burn out the ash to a lower combustible content results

in air leakage through back part of the fire and too much excess air loss, while cutting down the excess air too far involves undue combustible loss. The method is general; for this particular installation and fuel the best results were seen to be secured at 35 to 40% excess air, corresponding to 16 to 18% combustible in ash, although the latter could range from 12 to 22% (31 to 50% excess air) without materially affecting efficiency. The total loss curve, plotted direct from the boiler tests, and including loss due to incomplete combustion of gases and "radiation and unaccounted for," is seen to have its minimum at practically the same point as the lower curve. The three points enclosed in circles represent three tests run at extremely high boiler ratings with resulting high flue temperatures and high stack losses.

E. G. Bailey describes a method of investigating ash-pit losses from chain-grate stokers by the use of recording gas-tube thermometers of length equal to the stoker width, placed at a point near where the ashes are discharged from the active section of the grate, exposed to the radiant heat of the refuse but not to that of the furnace. The temperature reached depends on the amount of glowing coal surface exposed, and hence on the amount of ignited but unburned carbon, this relation being unaffected, for a particular installation, by grate speed, rate of combustion, percentage of ash in coal, or percentage of carbon in refuse. The instrument is calibrated by analyzing the coal and refuse, for the various temperatures, and calculating the % heat loss therefrom; for a bulb about 8 in below the grate surface and 5 in. behind the rearmost position of the links of a forced-draft stoker, 250° F corresponded to 3% ash-pit loss, and 700° F. to 7½% loss. Characteristic loss curves can be plotted, using this record and that from a steam- and air-flow meter, as in the accompanying chart
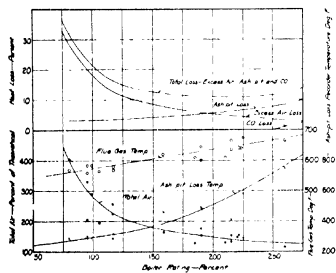
CHARACTERISTIC LOSS CURVES
FOR FORCED DRAFT CHAIN GRATE
—A.S M.E.

for a forced-draft chain grate. The three losses shown—unburned combustible in ashes, unburned gas, and excess air—depend almost entirely on the stoker and its operation, and such curves can be used to compare the relative efficiencies of different types of stokers, the suitability of different kinds of coal, and the effectiveness of the control by the fireman. The conditions can thus be determined which give the highest efficiency of the stoker and furnace, independently of the boiler, even though one may not be able to determine the exact value of the thermal efficiency in question.

8. **Unaccounted-for Heat.**—All of the above seven items are added together, and subtracted from the total heat value of 1 lb of dry coal, or 1 lb. of coal as fired, according to the basis on which the heat balance is being computed, and the difference is termed the heat loss unaccounted for. This includes loss due to *unconsumed* hydrogen and hydrocarbons passing out in the flue gases, and to heat escaping by radiation, etc., from the boiler and setting. It also includes the errors of observation, which are by no means small, particularly in sampling flue gases and determining their temperature.

The *Wickes Boiler Co.* mentions the following sources of loss under this head:

1. Porous and uncovered brick used in setting.
2. Setting not insulated and uncovered
3. Walls too thin and large joints of mortar uncovered.
4. Drum heads and shells uncovered.
5. Walls heated to very high temperature
6. Hydrogen loss when moist coal is fired on white hot coke, due to chemical reaction $2H_2O + C = CO_2 + 2H_2$.
7. Carbon monoxide and hydrogen when water comes in contact with coke, due to $C + H_2O = CO + H_2$.

H. D. Fisher states that in a series of tests where the conditions were such that there was a marked evolution of hydrogen and hydrocarbon gases, and where the flue gases were carefully analyzed for these constituents, the loss due to them about equaled that due to unburned CO. Appreciable amounts of CO in the stack gases generally indicate the presence of other combustible gases.

Absolute **radiation** losses are uncertain, but *Fisher* suggests the following averages for total unaccounted-for losses:

> 12 to 15% for small boilers at low rates,
> 7 to 8% for fair-sized units at average loads,
> 2 to 3% for very large boilers at high rates.

W. M. Selvey, referring to English practice, says that the radiation loss is no more than 3% in a boiler evaporating 20,000 lb. of water per hr., when the boiler is well lagged. The figure may be taken to be 2% for a 30,000 lb. per hr boiler, and for larger sizes Excessive radiation is always easy to locate, and not difficult to remedy.

F. A. Shorkey gives the charts on page 600 for the graphical determination of heat losses in boiler and furnace, with the following example of their use.

COAL ANALYSIS:		As Fired	Dry Basis
Fixed carbon	.	63 4%	65 0%
Volatile matter	..	26 38	27 0
Ash	. . .	7.8	8 0
Moisture .	. . .	2.42	2 55
§Sulphur ..		2 93	3 0
§Hydrogen		4 59	4 75
Total carbon .	..	77 5	79 5
BTU per lb	.	14,150	14,500
Combustible in refuse		20%	
CO_2 in flue gas	.	14%	
Flue gas temperature	.	600° F.	

§Estimated from charts on p. 47 if proximate analysis only is available

Enter Fig. 1 from left at 600°, right to the nearly vertical line for 2.55% moisture, down to 14,500 BTU, read at bottom 33 BTU loss due to moisture or (right) 0.23%. Enter Fig. 2 at 600°, right to 4 73% hydrogen, down to 14,500 BTU, read at bottom 548 BTU loss due to hydrogen and at right 3 8% Enter Fig. 3 at left at 20%. right to 8% ash. down to 14,500 BTU, read at bottom 295 BTU loss due to combustible in refuse, and at right 2%. In Fig. 4. from 295 BTU and 3% sulphur read sulphur and refuse correction as — 0.0035, which subtracted from the value 0.795 for carbon in fuel, gives 0.7915 lb. equivalent carbon burned. Enter Fig 5 at 600°. right to 14% CO_2. up to 0.7915, right to 14,500 BTU, read at right 1825 BTU loss in dry flue gas, or (at top) 12.6%. (Fig. 5 assumes that no CO is present in the flue gas and that the maximum theoretical CO_2 would be 19%, but the error due to any slight variation from these assumptions can in most cases be ignored. If CO is present, the loss in sensible heat of dry flue gas can be calculated by the usual formulas, and the loss represented by the CO itself read from Fig. 6, entering at left, following right to CO_2 line, then down to equivalent % carbon burned (from Fig. 4) and right to initial BTU per lb., then up to % loss in CO, or right to BTU loss per lb. dry fuel. In the example given, allowing 4% for radiation, etc., the boiler efficiency is calculated by difference to be 77.37%.
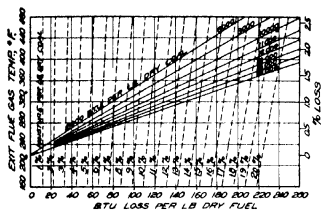
1. LOSS DUE TO MOISTURE IN COAL
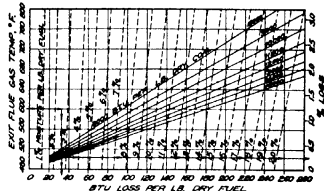
2. LOSS DUE TO HYDROGEN IN COAL
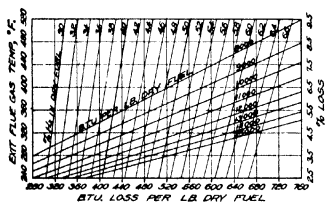
3. LOSS DUE TO COMBUSTIBLE
   IN REFUSE
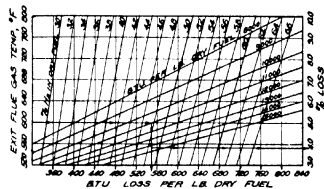
4. SULPHUR CORRECTION
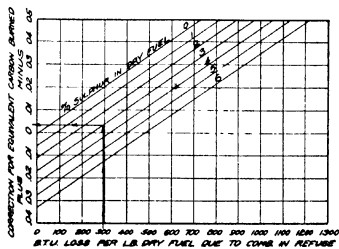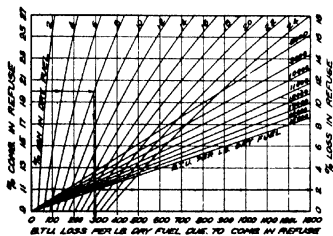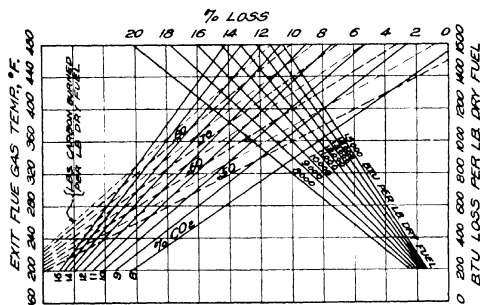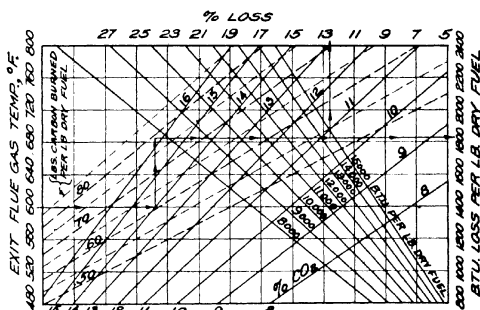
5. LOSS IN DRY FLUE GAS
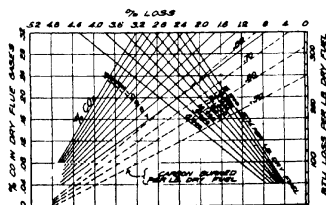
6. LOSS DUE TO *CO* IN FLUE GAS

SPECIMEN SHORT FORM HEAT BALANCE COMPILED AS DESCRIBED IN PAGES 586-598

24-HOUR TEST OF 2400-HP. BOILER, OPERATED AT 137% RATING

Coal as fired, 76.87% C, 5.31% H, 7.19% ash, 1.80% moisture, 13,810 BTU per lb.

Dry coal $= 98.2\%$ of coal fired.

Dry-coal basis, 78.30% C, 5.41% H, 7.32% ash, 1.83% moisture, 14,090 BTU per lb.

Coal fired 246,000 lb. $= 241,500$ lb. dry coal. Refuse produced 21,375 lb. $= 8.88\%$ of dry coal. Contains 17% combustible.

Flue gas analysis, 14.6% CO_2, 0.36% CO, 6.14% O_2, 78.9% N_2.

Water evaporated, 2,480,000 lb. Steam pressure 160 lb. gage, superheat 100°, $H_1 = 1254$ BTU per lb., above 32° F.

Average temperatures: Feed water 220° F., flue gas 560° F., room 72° F., air 63% saturated.

		BTU per lb. dry coal	% of total heat
1.	Absorbed by boilers: $$\frac{2,480,000\,[1254 - (220 - 32)]}{241,500}$$	10,960	77.8
2.	Lost by evaporation of moisture in coal: $.0183\ [1089 + (0.46 \times 560) - 72]$	23	0.2
3.	Lost in steam from hydrogen of coal: $.0541 \times 9 \times [1089 + (0.46 \times 560) - 72]$	620	4.4
4.	Lost in heating moisture of air: 63% at 72° F. $= .0168 \times 0.63 = .0105$ lb. moisture per lb. air. $0.783 - (.0888 \times 0.17) = 0.7679$ lb. carbon burned per lb. dry fuel. $0.7679 \times [(11 \times 14.6) + (8 \times 6.14) + (7 \times 0.36) + (7 \times 78.9)] \div [(3 \times 14.6) + (3 \times 0.36)] = 13.05$ lb. dry gas per lb. dry fuel. $13.05 + (9 \times .0541) - (1.00 - .0888) = 12.63$ lb. air per lb. dry fuel $.0105 \times 12.63 \times 0.46\ (560 - 72)$	30	0.2
5.	Lost in dry chimney gases: $13.05 \times 0.24\ (560 - 72)$	1,528	10.9
6.	Lost in unburnt CO: $10160 \times 0.7679 \times 0.36 / (14.6 + 0.36)$	188	1.3
7.	Lost in combustible refuse: $14600 \times (.0888 - .0732)$	228	1.6
8.	Unaccounted for (radiation, unburned hydrocarbons, errors of observation)	513	3.6
		14,090	100.0

BOILER TEST CODE

The *1923 Power Test Code* of the *American Society of Mechanical Engineers, 29* West 39th Street, New York City, states that with separate economizers, having their own housing and connected to the boilers with flues, the observations may be so made as either to include or exclude the economizer in the results. With integral economizers, contained within the boiler setting and through which a part of the boiler circulating water may or not pass, it is practically impossible to segregate the economizer from the boiler, and tests of such units should be conducted as if the economizer were a part of the boiler, with explanatory note.

Boiler testing should not be undertaken by anyone who has not had some training under an experienced testing engineer It is much easier to make mistakes than is realized by those who are not familiar with practical testing. Even with a carefully conducted test there are indeterminate errors in sampling coal, flue gas, moisture in coal, and moisture in steam, but the limits of accuracy of a test may very reasonably be taken to be within plus or minus 3%. In general results should be reported only to the nearest significant figure. Reporting results of any kind in small units is likely to convey an erroneous idea as to the real accuracy of the figures. In guarantee tests a limit of tolerance, both as to fuels used and results, should be agreed upon beforehand, which might well bear some relation to the care exercised in arranging the details and in the conducting of the test. The object of the test should be determined and recorded, with an agreement made before the test concerning all matters about which dispute may arise. The dimensions and physical conditions should be noted, examination made for leakage, and apparatus installed where it will be subject to inspection by those in charge and protected from disturbing influences.

Measurements— The quantities listed below are the principal ones which must be measured in a performance test of a stationary steam boiler.

    (*a*) Area of heating surfaces
    (*b*) Grate surface
    (*c*) Furnace volume and dimensions
    (*d*) Analysis and heating value of fuel
    (*e*) Average steam pressure
    (*f*) Draft pressures at various points
    (*g*) Steam temperatures
    (*h*) Superheat
    (*i*) Various air temperatures
    (*j*) Temperatures of gases
    (*k*) Feedwater temperatures
    (*l*) Total weight of fuel
    (*m*) Weight of refuse.

Draft at the gas outlet is usually measured if nowhere else. It is often desirable to know the draft at other points of the setting, in which cases the several locations should be chosen to suit the information wanted. Care should be exercised to see that the ends of the connecting pipes are not obstructed and that the open ends are not subject to other than static pressures. All joints of draft-gage connections must be tight. A *thermometer* well for measuring feedwater temperatures should be as close to the boiler inlet as possible and the pipe between boiler and thermometer should be well protected with heat-insulating covering. Saturated-steam temperatures may be measured at any point in the steam pipe where the pressure is the same as that where the temperature is desired, care being taken that the well is not cooled by the condensate. The temperature and pressure of superheated steam should be measured as close to the outlet of the superheater as possible, eliminating all losses by pressure drop and radiation between the superheater and thermometer. Pyrometers of any type must have the part on which the heat impinges so located that the temperature which it is desired to measure is actually obtained.

Starting and Stopping— Combustion, fuel, draft, and temperature conditions, the water level, rate of feeding water, rate of steaming, and the steam pressure should be as nearly as possible the same at the end as at the beginning of the test. If an economizer is included in the unit tested the average temperature of the water within it should be the same at the start and end of test.

With *hand-fired* boilers the following method should be employed: The furnace being well heated by a preliminary run at the same combustion rate that will prevail during the test and sufficiently long to thoroughly heat the setting, burn the fire low and thoroughly clean it, leaving enough live coal spread evenly over the grate (say, from 2 to 4 in) to serve as a foundation for the new fire Note quickly the thickness of the coal bed as nearly as it can be estimated or measured, also the water level, the steam pressure, and the time, and record the latter as the starting time. Fresh coal should then be fired from that weighed for the test, the ashpit thoroughly cleaned, and the regular work of the test proceeded with. Before the end of the test the fire should again be burned low and cleaned in such a manner as to leave the same amount of live coal on the grate as at the start. When this condition is reached, observe quickly the water level, the steam pressure, and the time, and record the latter as the stopping time. If the water level is lower or higher than at the beginning, a correction should be made by computation, not by feeding additional water. Finally remove the ashes and refuse from the ashpit In a plant containing several boilers, where it is not practicable to clean them simultaneously, the fires should be cleaned one after the other as rapidly as may be, and each one after cleaning charged with enough coal to maintain a thin fire in good working condition. After the last fire is cleaned and in working condition, burn all the fires low (say, 4 to 6 in), note quickly the thickness of each, also the water levels, steam pressure, and time, which last is taken as the starting time. Likewise, when the time arrives for closing the test the fires should be quickly cleaned one by one, and when this work is completed they should all be burned low the same as at the start, and the various final observations made as before stated. In the case of a large boiler having several furnace doors requiring the fire to be cleaned in sections one after the other, the above directions pertaining to starting and stopping in a plant of several boilers may be followed.

Stokers should be in operation at approximately the same rate that will prevail during the test for at least 12 hrs. before starting test At the start and finish of the test, level the coal in stoker hopper Make starting and stopping observations as in hand-fired tests. With the continuous-dumping type the desired operating conditions, *i.e.*, speed and stroke of coal-feeding mechanism, speed of grate, intensity of draft or blast, and rate of water feed, should be maintained as nearly constant as possible for at least one hour, and preferably for 2 hr , before starting and stopping the test. With the intermittent-dumping type, proceed as above except that stokers should be cleaned about 1 hr before starting and before stopping the test

When *pulverized, liquid or gaseous* fuel is used, the following method should be employed: The boiler or boilers to be tested should be operated before the start of the test under the fuel, furnace, and combustion conditions which are to be maintained throughout the test for a period of not less than 3 hr. Fuel temperature, fuel pressure and draft conditions should be kept as nearly constant as possible during this period and throughout the test.

In the case of a *waste-heat* boiler set in connection with an industrial furnace the operation of which is continuous, the rules governing the starting and stopping of tests with pulverized liquid, or gaseous fuels will apply Where the industrial furnace operates in cycles the start and end of the test should be at the same point of two or more successive cycles

Duration— The duration of tests to determine the efficiency of a steam boiler burning *coal,* either hand or stoker fired, should preferably be 24 hr., but where operating conditions do not permit or other considerations make it advisable or necessary the length of test may be reduced to not less than 10 hr. When the rate of combustion is less than 25 lb. of coal per sq. ft. of grate surface per hr., the test should be continued until a total of 250 lb. per sq. ft. of grate area has been burned, except that in cases where a type of stoker is used that does not permit the quantity of fuel and the condition of the fuel bed to be accurately estimated the duration of test should not be reduced below that required to minimize the error.

When using *pulverized fuel* the duration of test should be not less than 6 hr., and for *liquid* or *gaseous* fuel not less than 4 hr. In the case of a *waste-heat* unit, where the operation of the industrial furnace is continuous and furnace conditions are constant, the test should be not less than 6 hr Where the operation is in cycles, the test should cover at least one cycle of furnace operation
In tests where the service requires *continuous operation* night and day, with frequent shifts of firemen, the duration of test should be at least 24 hr. Likewise in such tests, either of a single boiler or of a plant of several boilers which operate regularly a certain number of hours and during the remainder of the day are banked, the duration should be not less than 24 hr The duration of tests to determine the *maximum evaporative capacity* of a steam generating installation when the efficiency is not determined, should be not less than 2 hr , unless otherwise agreed upon.

Records—The data listed in the tables of the code should be obtained and recorded in convenient form Readings of the instruments at 15-minute intervals are usually sufficient If there are sudden and wide fluctuations, the readings should be taken at 10-minute intervals, or at such frequency as may be necessary to determine a good average.

The approximate quantity of *fuel* needed each hour should be determined, and if the quantity required and inconvenience due to lack of room is not too great, the whole amount should be delivered on the firing floor at the beginning of each hour. If any is left at the end of the hour the quantity should be estimated. In this way the amount of fuel used per hour can be determined and the approximate results be followed from hour to hour. If the whole amount cannot be delivered at the beginning of the hour, convenient quantities may be weighed out at appropriate intervals so as to come out about even at the end of the hour When hopper scales are used, receiving coal from bunkers and discharging directly into furnace hoppers, hourly quantities may be roughly determined by estimating furnace conditions These hourly quantities should be properly noted on the log sheet. They are taken as a matter of convenience and guide, but only the totals are to be used in the final calculations.

The records should be such as to ascertain also the approximate consumption of feedwater each hour, and thereby determine the degree of uniformity of *evaporation.* The maintenance of a uniformity of evaporation is greatly facilitated by the use of some form of graphic recording steam meter, which should be so placed as to keep continuously before the operator the rate of evaporation Since the indications of this meter are not used in any of the test calculations, extreme accuracy is not essential. If the boiler does not produce superheated steam, the *quality* of the steam should be determined by the use of a throttling or separating calorimeter. If the boiler has superheating surface, the temperature of the steam should be determined by the use of a thermometer inserted in a thermometer well, as described in the above-mentioned code.

The *ashes and refuse* withdrawn from the furnace and ashpit during the progress of and at the end of the test should be weighed, as far as possible, in a dry state. If wet, the amount of moisture should be ascertained and allowed for, a sample being taken and dried for this purpose. This sample may also serve for analysis.

Ash sampling is at best subject to large errors, and every precaution should be taken to insure as representative a sample as possible If sufficiently hot to allow combustion to proceed, ash should be thoroughly quenched with water immediately after dumping into the ashpit. Enough time should elapse before weighing to permit the heat of the refuse to drive out most of this moisture. If possible, all the ash should then be passed through a crusher, thoroughly mixed, and reduced to a laboratory-size sample by successive quartering If it is impracticable to crush all the ash, the clinkers and fines should be placed in separate piles, and each pile weighed and sampled separately, the two samples being combined in proportion to the relative weights of their respective piles
Heating surface shall consist of that portion of the surface of the heat-transfer apparatus exposed to both the gases being cooled and the fluid being heated at the same time (computed on the gas side). Furnace volume is the cubic space provided for the combustion of fuel before the products of combustion pass through any heating surface.

Gas samples should preferably be taken continuously, but if momentary samples are obtained the analyses should be made as frequently as possible, noting the furnace and firing conditions at the time the samples are drawn. Where the firing is intermittent, gas samples should be taken at such intervals that the complete firing cycle will be covered by the average of individual readings. If the sample drawn is a continuous one the intervals may be made longer. Where the unit includes an economizer, gas analyses should be made at both boiler and economizer outlets.

It is recommended that a record be kept of the energy used by *auxiliaries* immediately connected with the steam generating unit being tested and a specific note made thereof; no deductions, however, shall be made on the report forms or in computing results unless the object of the test so requires, in which case the report should specifically so state. This applies to steam or power used in driving stokers or other fuel-feeding apparatus, oil burners, fans, feed pumps, soot blowers, etc. In trials having for an object the determination and exposition of the complete boiler performance, the entire log of readings and data should be represented *graphically*.

Heat Balance— The *Short Form Heat Balance* is discussed on pp. 586 to 602. More detailed studies can be made according to the *A.S.M.E.* methods described in the following:

DETAILED HEAT BALANCE OF STEAM GENERATING UNIT COMPRISING BOILER, WITH OR WITHOUT INTEGRAL ECONOMIZER (Solid Fuels)

	Heat Values	BTU per lb, as Fired or Dry	%
2094	Heat per lb. *coal* (higher heating value)	.. ....	....
2095	Heat absorbed by water and steam in boiler (including economizer, if any) and superheater.	....	....

$= (H_1 - h_{b1}) \times W$

$H_1 =$ total heat of steam as delivered, *BTU* per lb. (p 590), $h_{b1} =$ total heat of feedwater at boiler inlet, $W = $ lb water actually evaporated per lb. coal.

| 2096 | Heat absorbed by steam in superheater . . . . | .... | .... |

$= (H_1 - H) \times W$

$H =$ total heat of dry saturated steam at boiler outlet pressure.

Unavoidable Losses:

| 2097 | Heat loss due to *moisture* in coal, *moisture* accompanying theoretical air, and water from combustion of *hydrogen*, up to *boiler water temperature*. . . . . | .... | .... |

$= (1089 + 0.46T_{11} - T_{12}) \times (M_c + 9H_c)/100 + (G_t - C_b) \times M_a \times 0.46 \times (T_{11} - T_4)$

$T_{11} = ° $ F. boiler water at gas outlet, $T_{12} = ° $ F.. fuel as fired, $T_4 = ° $ F., air for combustion, $M_c = \% $ moisture in coal, $H_c = \% $ hydrogen in coal, $M_a = $ lb. moisture in air per lb.

$C_b =$ carbon burned per lb. coal (p. 594).

$G_t =$ theoretical lb. dry gas per lb. fuel $= (12.52 \times C_b) + (26.56 H_c + 3\ 325\ S_c + N_c)/100$

S_c and $N_c = \% $ sulphur and nitrogen in fuel.

| 2098 | Heat loss due to *theoretical dry gases*, up to *boiler water temp*... | .... | .... |

$= G_t \times (T_{11} - T_4) \times 0.24$

| 2099 | Total unavoidable losses. . . . . | .... | .... |

Other Losses:

2100 Heat loss due to combustible in refuse.....   . ...
       $= 14600 \ (R - A_a)/100$
       R = refuse, % of fuel (p. 594). A_a = ash in fuel by analysis, %.

2101 Heat loss due to *sensible heat* in refuse, cinders and soot .   .. .
       Determinable only where refuse is discharged into water, = lb of
       quenching water used $\times$ its temperature rise.

2102 Heat loss due to unburned *gaseous combustibles*.. .   .   . .
       $= 10160 \times C_b \times CO/(CO_2 + CO)$
       CO_2 and CO = % by volume in outlet gases.

2103 Heat loss due to *excess air* entering furnace and moisture accom-
       panying same, up to *boiler water temperature*.. .   .   .   .
       $= (Gt - Gt) \times (T_{11} - T_4) \times (0.24 + 0.46 \ M_a)$
       Gt = actual dry gases per lb. fuel, from furnace gas analyses (p.
       594).

2104 Heat loss due to *theoretical dry gases*, moisture in coal, moisture
       accompanying theoretical air, and moisture from combustion of
       hydrogen, from boiler water temp. to *exit gas temp.*   ....
       $= (T_6 - T_{11}) \times [(Gt \times 0.24) + (Gt - C_b) \ M_a + 0.46 \ (Mc + 9 \ Hc)/100]$
       $T_6 = °$ F., gases leaving boiler.

2105 Heat loss due to *excess air* entering furnace and moisture accom-
       panying same, from boiler water to *exit gas temp*...   ....
       $= (Gt - Gt) \times (T_6 - T_{11}) \times (0.24 + 0.46 \ M_a)$

2106 Heat loss due to air and moisture *leaking* through setting, room
       temp. to exit gas temp.
       $(G_{bo} - Gt) \times (T_6 - T_1) \times (0.24 + 0.46 \ M_a)$
       G_{bo} and Gt = lb. dry gases per lb fuel, from analysis of gases
       leaving boiler and in furnace.
       $T_1 = °$ F., air surrounding boiler.

2107 Heat loss due to unconsumed hydrogen and hydrocarbons, *radiation*,
       and *unaccounted for* . . ..
       $= It. \ 2094$ — sum of items 2095 and 2099 to 2106.
       NOTE—*Items* 2098, 2103, 2104, 2105 and 2106. 0.24 is the value
       in common use for the specific heat of dry flue gases. This value is
       not exactly correct and if extreme accuracy is desired the true
       specific heat should be calculated from the gas analysis.
       NOTE—*Items* 2097, 2104, and 2106   These formulas are correct
       only when the total moisture in the gases is less than that necessary
       to saturate the gases of the final temperatures indicated. If the
       relation of moisture and temperature is such that some moisture
       will be condensed, these items should be corrected for the heat given
       up by the condensing vapor.

Separate Economizers—The heat absorbed in units having separate economizers
can be classified as follows:
       Absorbed by water and steam in boiler and superheater
       $= (H_1 - h_{b1}) \times W$
       Absorbed by steam in superheater
       $= (H_1 - H) \times W$
       Absorbed by water in economizer
       $= (h_{b1} - h_{e1}) \times W$
       H_1 = total heat of steam as delivered, H = total heat of dry saturated steam at
boiler outlet pressure, h_{b1} = total heat in feed water at boiler inlet, h_{e1} = total heat
of water at economizer inlet, all in BTU per lb
       The calculation of the remaining items is modified so as to cover the boiler and
economizer as a single unit, except that in 2106 the two settings can be considered
separately if appropriate gas analyses are available.
       The efficiency of the economizer alone is
       $(h_{b1} - h_{e1}) \ W$

$$(T_6 - T_{10}) \ [0.24 \ G_{bo} + 0.46 \ (G_{bo} - C_b)M_a + 0.46 \ (Mc + 9 \ Hc/100)]$$
       Where $T_6 = °$ F., gases leaving boiler, $T_{10} = °$ F., feedwater entering economizer.
       That of the complete unit is
       $(H_1 - h_{e1}) \times W/$Htg. value per lb. fuel.

Air Heaters.—An installation including an air heater is figured as a complete unit, considering the several items up to T_8, ° F. of gases leaving air heater.

Efficiency of air heater

$$= \frac{(T_3 - T_2) \times (0\ 24 + 0\ 46\ M_\mathrm{n})}{0.24\ (T_7 - T_2)}$$

$T_3 =$ ° F., air leaving heater, $T_2 =$ ° F , air entering heater, $T_7 =$ ° F. gases entering heater.

Efficiency of unit

$$= (H_1 - h_{\mathrm{el}}\ \mathrm{or}\ h_{\mathrm{bl}}) \times W/\mathrm{Htg.\ value\ per\ lb.}$$

Comparative efficiency of same outfit with air heater omitted

$$= \frac{(H_1 - h_{\mathrm{el}}\ \mathrm{or}\ h_{\mathrm{bl}}) \times W}{\mathrm{Htg.\ value\ per\ lb.} + (T_4 - 70) \times A_1 \times 0\ 24}$$

$T_4 =$ ° F., air for combustion (from heater), $A_1 =$ air supplied per lb. fuel (p. 594)

Liquid Fuels.—Method same as for solid fuels, except no loss in refuse, and carbon burned per lb coal, C_b, $= C_e/100$

Gaseous Fuels.—Fuel-gas analysis should be reported on dry basis *by weight.* Where BTU value is calculated it is on dry basis. Where determined on calorimeter should be corrected for moisture. If fuel temp , T_{12}, is greater than room temp. T_1, add mean specific heat $\times (T_{12} - T_1)$ to the calculated BTU value. Standard conditions are 29.92 in mercury and 68 ° F.

$C_b =$ carbon burned per lb. fuel $=$ carbon content of fuel gas, lb per lb.

$= \frac{3}{7}\ CO + \frac{3}{4}\ CH_4 + \frac{12}{13}\ C_2H_2 + \frac{6}{7}\ C_2H_4 + \frac{4}{5}\ C_2H_6 + \frac{3}{11}CO_2,$

where CO, etc , are *fractions,* by *weight,* in the fuel gas.

$G_t =$ theoretical dry gas per lb. fuel

$= 3\ 46\ CO + 26\ 56\ H_2 + 16\ 03\ CH_4 + 13\ 6\ C_2H_2 + 15\ 52\ C_2H_4 + 15\ 33\ C_2H_6$
$+ 6\ 58\ H_2S + 1.00\ N_2 + 1\ 00\ CO_2$

where CO, etc., are fractions by weight in the fuel gas.

Flue gas analyses left in volumetric form, as with solid or liquid fuels.

VALUE OF BOILER TESTS

The evaporative test has its uses, but it does not serve to fix the individual causes of fuel losses. To yield reliable and valuable information requires team work by a number of experienced and disinterested men. The temptation to take advantage of many little things is almost too much for ordinary human nature. So many things can be done under the nose of an inexperienced engineer that all such tests should be taken with a wide margin of allowance for errors, both unintentional and otherwise.

Hays mentions a trick of having a boiler steaming heavily at the start of a test. This gives a high false water level. At the end of the test, the fire is allowed to simmer down, so that the water level will drop, which requires a large quantity of water to be pumped in to bring the level to the original mark. The amount may come to 10% of the total water evaporated.

It is well to break the blow-off line, so that any leakage from the boiler can be detected.

In a discussion of the accuracy of boiler tests, *Alfred Cotton* states that if the water is carefully weighed or measured by suitable meters, the amount fed may be ascertained well within $\pm 1\%$, and that meters can be calibrated before, and perhaps after a test, to insure this accuracy. Precautions may be taken to prevent leaks from blow-off cocks, in feedwater heaters, etc. The difference in specific gravity of cold water in the gage connections before blowing off the gage and of hot water afterward may affect the calculated water content of the boiler sufficiently to cause an error in total evaporation of more than 1% in an 8-hr. run at rating. The temperature of the steam in the expansion chamber of a throttling calo-

rimeter need only be read to the nearest degree, and the average to one-tenth degree. He claims that the *A. S. M. E.* steam sampling tube, made of ½-in. standard pipe and provided with twenty ⅛-in holes arranged in irregular or spiral rows, has a water-collecting power averaging over four times the actual water content of the bulk steam flow, and recommends placing the holes in a line facing directly upstream instead of distributed around the tube. If there is much priming, the amount of water carried over may approach 5% of that evaporated, but assuming orderly operation and careful observation, the accuracy of the report on water evaporated may be ± 1½% to 2%, but it cannot well be guaranteed to be closer.

Coal can be weighed within ± 1%, but estimates as to amount of coal in the furnace may vary as much as 10 or 20 lb. per sq. ft. of grate area, and for a 12-hr. test the error may reasonably be placed at not less than ± 1%. With difficulty of collecting and analyzing samples, the moisture cannot be certified closer than ± 1%, and may be out ± 2%. If the coal is dried during the test, with crude drying and weighing apparatus, but with reasonable care in selecting samples, results may be obtained within ± 1%.

He summarizes the possible errors as follows, keeping them lower than suggested above:

	Error
COAL	
Weighing	± 0 5%
Estimating amount of fuel in furnace at start and stop	± 0.5%
Total error of weighing coal...........	± 1.0%
Variation between original percentage of moisture and that in laboratory sample plus failure of sample truly to represent bulk....	± 1.0%
Failure of heating-value sample to represent bulk...	± 0.5%
Total error in analysis	± 1.5%
Total error in *BTU* in coal (weight and analysis on which efficiency is based	± 2.5%
WATER	
Weighing or metering, starting and stopping test, gage glass, leaks...	± 0.5%
Failure of sample of steam to truly represent bulk steam as to entrained water	± 0.5%
Total error in water evaporated.............. .....\...............	± 1.0%

BTU in coal burned may vary 97 5 to 102 5%.
Water evaporated may vary from 99 0 to 101 0%
Reported efficiency may vary from 99 0/102.5 to 101 0/97 5, = 96 6 to 103.6% of true efficiency.

Hence if the efficiency is really 78%, the report may show as low as 75.4% or as high as 80 8%, if the errors are in one direction. If a sufficiently large number of trials are made on the same boiler under the same conditions, some of the tests will nearly always be found to deviate from the average quite as much as the total possible error here suggested. If the coal and water deductions are to be relied on, we know the efficiency and the load, but *Cotton* doubts if the regular carefully-conducted boiler test burning hand- or stoker-fired coal can be guaranteed to be closer than within ± 3%. The "unaccounted-for" losses in one of the most careful series of trials ever made ranged from 1.51 to 4.83%, and the real value

of a heat balance lies in the presentation of the various losses and their amounts, it being more a *statement* than a *balance*.

CO_2 may vary as much as 5% across the width of the setting, although some of this may be caused by quality of the gases changing rapidly between taking samples. It seems likely that if the gas sample is drawn from some point well within the gas flow it is fairly representative, as otherwise the "unaccounted-for" losses would show a larger variation. Radiation may affect the exit gas temperature readings by 50° F., but with care in placing the instruments the error is perhaps within ± 20° F., or about ±1% in stack heat loss.

CONVERSION FACTORS

DENSITY, SPECIFIC VOLUME AND SPECIFIC HEAT OF WATER AT DIFFERENT TEMPERATURES

(From Marks and Davis's Steam Tables)

Temp., deg. fahr.	Pressure, lb. per sq. in	Specific volume, cu ft. per lb	Density, lb. per cu ft.	Specific heat	Temp., deg. fahr.	Pressure, lb. per sq. in.	Specific volume, cu ft. per lb.	Density, lb. per cu. ft.	Specific heat
20	0.06	0 01603	62.37	1 0168	240	24 97	0 01692	59 11	1 012
30	0 08	0 01602	62 42	1 0098	250	29 82	0 01700	58 83	1 015
40	0 12	0 01602	62 43	1 0045	260	35 42	0 01708	58 55	1 018
50	0.18	0 01602	62 42	1 0012	270	41 85	0 01716	58.26	1 021
60	0.26	0 01603	62.37	0 9990	280	49.18	0 01725	57.96	1 023
70	0 36	0 01605	62 30	0 9977	290	57 55	0 01735	57 65	1 026
80	0 51	0 01607	62 22	0 9970	300	67 00	0 01744	57 33	1 029
90	0 70	0 01610	62 11	0 9967	310	77 67	0 01754	57 00	1 032
100	0 95	0 01613	62 00	0 9967	320	89 63	0 01765	56 66	1 035
110	1.27	0 01616	61 86	0 9970	330	103.0	0 01776	56.30	1 038
120	1.69	0 01620	61 71	0 9974	340	118 0	0 01788	55 94	1 041
130	2 22	0 01625	61 55	0 9979	350	135 0	0 01800	55.57	1 045
140	2 89	0 01629	61 38	0 9986	360	153 0	0 01812	55.18	1 048
150	3 71	0 01634	61 20	0 9994	370	173 0	0 01825	54.78	1 052
160	4.74	0 01639	61 00	1 0002	380	196 0	0 01839	54.36	1 056
170	5 99	0 01645	60 80	1 0010	390	220 0	0 01854	53 94	1 060
180	7 51	0 01651	60 58	1 0019	400	247 0	0 0187	53 5	1 064
190	9.34	0 01657	60 36	1 0029	410	276 0	0 0189	53 0	1 068
200	11 52	0 01663	60 12	1 0039	420	308 0	0 0190	52 6	1 072
210	14 13	0 01670	59 88	1 0050	430	343 0	0 0192	52.2	1 077
220	17 19	0 01677	59 63	1 007	440	381 0	0 0194	51 7	1.082
230	20 77	0 01684	59 37	1 009					

Water at 60° F. weighs 58,361 grains per U. S. gal.
　　　　　　　　　8 337 lb. per U. S. gal.
　　　　　　　　　62.3677 lb. per cu. ft.

1 atmosphere (standard) = 760. millimeters of mercury.
　　　　　　　　　29.921 2 in. of mercury.
　　　　　　　　　33.906 6 ft. of water.
　　　　　　　　　14.696 9 lb. per sq. in.
　　　　　　　　　1.033 29 kilograms per sq. centimeter.

1 centimeter   = 0.393 700 in.
1 square centimeter = 0 155 000 sq. in.
1 U. S. gallon   = 231. cu. in.
                      0 133 681 cu. ft.
                      3.785 43 liters or cu. decimeters.
                      3785.43 cu. centimeters or milliliters.
                      32. gills
                      8. pints
                      4. quarts.
                      0.832 702 4 Imperial gal
1 grain   = 1/7000 lb. (av.)
                      0 002 285 71 ounce (av.)
                      0 064 798 9 gram
1 barrel water   = 31 to 31½ gallons

The specific heat of a substance at constant pressure is the number of
BTU required to raise the temperature of 1 lb. of the substance 1° F., the
pressure remaining constant   To be most exact the temperature range
should be given. The mean specific heat is the average of the specific heats
for each degree within the range considered.

The specific heat of a mixture of gases is obtained by multiplying the
specific heat of each constituent gas by the fraction by weight of that gas
in the mixture and adding the products. See page 176. For flue gases
at stack temperatures the average value is 0 24.

MEAN SPECIFIC HEATS AT CONSTANT PRESSURE FOR TEMPERATURES
USUALLY ENCOUNTERED

O_2 217		Flue gases.. .24 average	
N_2 247		H_2O vapor.. .48	
H_2 ....3.42		H_2O 1	
Air .... .24		Fe .... .168 (32° to 2000° F.)	
CO .... .243		Cu .... 09 (32° to 212° F.)	
CO_2 .... .21			

DENSITY OF GASES AT 32° F AND 29 92 IN OF MERCURY.—*Steam*, adapted
from Smithsonian Tables.

Gas	Chemical Symbol	Specific Gravity Air=1	Weight of One Cubic Foot Pounds	Volume of One Pound Cubic Feet	Relative Density, Hydrogen=1	
					Exact	Approximate
Oxygen	O	1 053	.08922	11 208	15 87	16
Nitrogen .	N	0 9673	.07829	12.773	13 92	14
Hydrogen . . .	H	0 0696	.005621	177 90	1 00	1
Carbon Dioxide .	CO_2	1 5291	.12269	8 151	21 83	22
Carbon Monoxide .	CO	0 9672	.07807	12 809	13 89	14
Methane . .	CH_4	0.5576	.04470	22 371	7 95	8
Ethane . .	C_2H_6	1 075	.08379	11 935	14 91	15
Acetylene . . .	C_2H_2	0 920	07254	13.785	12 91	13
Sulphur Dioxide . .	SO_2	2 2639	.17862	5 598	31 96	32
Air	. . .	1.0000	.08071	12 390	. . .	. . .

Wm. L. DeBaufre suggests the analysis of power plant performance on the basis of the "second law of thermodynamics," using the following relations:

(1) $Q_o = (T_o/T) Q$
(2) $Q_o = T_o (S_1 - S_2)$
(3) $Q_o = T_o [0.24 \ log_e \ (T_1/T_2) + 00002 \ (T_1 - T_2)]$

where, for any operation, Q_o is the energy which would necessarily be rejected by the working substance at temperature T_o, even by a perfect Carnot engine.

T_o is the abs. temperature ($^\circ$ F. + 460) of the "source of cold."

T is the abs. temperature of the source of heat.

Q is the heat supplied to the working substance at temperature T.

S_1 and S_2 are the entropies of the steam at the beginning and end of the withdrawal of heat supplied to perfect engine.

$log_e = 2.3 \ log_{10}$

He analyzes the performance of a locomotive for which the first-law balance was as follows, per lb. of dry coal:

Heat converted into work (*ihp*).	983 *BTU*	7.0%
Heat rejected in exhaust steam	7870	56.0
Heat lost in stack gases.............	1449	10.3
Heat lost by unburnt coal, etc. (by dif.)...	3742	26 7
	14,044	100.0

Boiler and furnace efficiency $= 7 + 56 = 63\%$.

The fourth item is also entered as unavailable in the second-law balance For firebox temperature of 2490° F and boiler-metal temperature 390° F, the radiation from fuel bed to heating surface, per sq ft. grate surface, is $(1600/1000^4)$ [$(460 + 2490)^4 - (460 + 390)^4$] ÷ 86 6 lb. dry coal per sq. ft grate $= 1390 \ BTU$ per lb. dry coal reaching heating surface by radiation. Letting this $= Q$, $T_o = 460 + 70$, feed-water temperature, and $T = 460 + 2490$; from formula (1) we get $Q_o = 250$ unavailable portion of radiant heat From formula (3), letting $T_1 = 460 + 2490$, $T_2 = T_o = 460 + 70$, $Q_o = 244 \ BTU$ unavailable energy in furnace gases per lb of gas × 13.40 lb. gas per lb dry coal $= 3270$ per lb. dry coal. Again in (3), letting $T_o = T_2 = 460 + 70$, $T_1 =$ the smokebox temperature, $494 + 460$ we get 79 29 unavailable per lb. smokebox gases, or $79.29 \times 13.40 = 1062 \ BTU$ per lb. dry coal unavailable energy in smokebox gases. 1449, from the first law balance, $- 1062 = 387 \ BTU$ per lb. dry coal, available energy in smokebox gases, but lost with these gases passing to the stack. From formula (2), letting $T_o = 460 + 70$, $S_1 =$ entropy for steam at 193 7 lb. gage and 555° F. $= 1.6486$, $S_2 =$ entropy for water at 70° F. $= .0746$, $Q_o = 834.2$ per lb. steam, × 7.03 lb. steam per lb. dry coal $= 5864 \ BTU$ per lb. dry coal unavailable in the superheated steam. $983 + 7870$, from first law balance, $- 5864 = 2989$ which would be available for conversion into mechanical work by a perfect engine after transmission through heating surface. $14,044 - 2989$ — sum of 4 items already determined $= 3406$ loss of available energy in process of heat transfer in boiler. In formula (2), letting $T_o = 460 + 70$, $S_1 =$ entropy of exhaust steam at 8 2 lb. gage, 263.1° F., $= 1 7252$. $S_2 =$ entropy of water at 70° F. $= .0746$. $Q_o = 874 8 \ BTU$ per lb. steam, or 6150 per lb. dry coal, unavailable energy in exhaust steam. 7870 from first-law balance, $- 6150 = 1720$ available for conversion into mechanical work by a perfect engine, but carried out by the exhaust. 983 is the heat transformed into work, and the final difference, 286 is termed loss of available energy due to imperfections in engine cylinders, although improvement in the cylinders would also reduce the loss of available energy in the exhaust.

SECOND-LAW BALANCE

	BTU per Lb. Dry Coal	%
Unavailable due to unburnt fuel, etc	3742	26.6
Unavailable part of radiant energy	250	1.8
Unavailable energy in firebox gases. ..	3270	23.3
Available energy lost in smokebox gases	387	2.8
Available energy lost by heat transfer .. .	3406	24.2
Available energy lost in exhaust.. . .	1720	12.3
Heat transformed into work	983	7.0
Available energy lost by imperfections in cylinder .	286	2.0
	14044	100 0

The loss due to heat transfer in the boiler is thus nearly one-quarter of the heating value of the fuel, and is the loss that is now being success-fully attacked and reduced by the use of higher steam pressures and fluids other than water, such as mercury. The exhaust loss is by this analysis reduced to less than ⅛, which is its correct relative importance. For a condensing plant, this loss is still less. While somewhat more com-plicated calculations are required than for the usual first-law balance, the facts revealed may more than justify its extended use.

EFFICIENCIES

The general definition of the efficiency of an apparatus is the ratio of the energy made use of by the apparatus to the energy available for its use.

The efficiencies of the different parts of a boiler installation and of the installation as a whole are defined in so many different ways that there is some confusion. The following definitions are used.

What is ordinarily called the efficiency of the boiler is in reality the efficiency of the boiler, furnace and grate, and is the heat absorbed per lb. of fuel divided by the heating value   The value obtained will be the same whether the efficiency is based on dry fuel or on fuel as fired. All the fuel cannot be burned, as some goes through the grates, and it is obviously un-fair to charge this to the boiler. On the other hand, the boiler user must pay for it, and is justified in charging it against the boiler and furnace.

"True boiler efficiency" is defined by the *Bureau of Mines* as the ratio of heat absorbed by the boiler to the heat available for the boiler. A boiler cannot absorb heat from a source below the temperature of the boiler con-tents, but the ordinary overall boiler efficiency charges the boiler with such heat. The more air used in the furnace the greater is the % of total heat below the boiler steam temperature.

Tests on the Torpedo Boat "Biddle" by the *Bureau of Mines* showed that the quantity of heat absorbed increases nearly at the same rate as the quantity of available heat. In other words, the true boiler efficiency is nearly constant. For most boilers, if combustion is fairly complete, over-all efficiency as well as true boiler efficiency will remain nearly constant with almost any rate of combustion. (See page 525 and following.)

Hays suggests that furnace efficiency should be considered apart from boiler efficiency. Gas analysis is the one and only means of furnace test-ing. For the purpose of study consider everything from the grate to the

damper except the naked boiler as a part of the furnace. Increase in furnace and grate efficiency without change of their design is primarily a question of air supply, generally a reduction of air supply.

For comparing the **steaming qualities** of two boilers a very careful study must be made of the conditions in each boiler. The overall efficiencies will not show a correct comparison, for the overall efficiency is affected by the size and character of the coal, the air spaces in the grate, the skill or lack of skill of the fireman in preventing the loss through the grate, the condition of the setting, and the entire method of operation, as well as the actual efficiency of the boiler itself. The "true boiler efficiency" should therefore be used in comparing two boilers.

EFFICIENCY OBTAINABLE WITH DIFFERENT COALS

High volatile coals generally do not give as good *efficiency* as high fixed-carbon coals. With hand firing, air is not admitted in sufficient quantities immediately after firing for at least 2 min. after the firing period, during which times most of the volatile is distilled. A little volatile is distilled in the succeeding minutes.

The efficiency drops and the percentage of heat loss unaccounted for increases as the ease of liberation of the **volatile** increases. The table below shows the results with various coals, tabulated in accordance with the ease of liberation of combustible and heavy hydrocarbon gases at 600° C. The amount of volatile is not entirely responsible for the incomplete combustion. The chemical composition and physical state also account for it.

EFFECT OF CHARACTER OF VOLATILE GASES IN FUEL ON
EFFICIENCY OBTAINABLE

Coal No.	Volatile matter in dry coal (per cent).	Combustible gas at 600°.[a]	Heavy hydrocarbon gases at 600°[a]	Steam test No.	Boiler efficiency (per cent)	Unaccounted- for loss (per cent).	CO in flue gas (per cent).	Rate of firing[b]
W. Va. 11............	20 8	60	5 6	56	68.3	5.4	0.05	18.1
Pa. 19............ ...	32.9	....	....	{498	63.9	8.7	.04	20.4
				{308	65 6	7 1	.02	21.0
Lab. 3........	30 4	75	8.5	....	......	.....	....	... ..
Ill. 19........	33 0	108	10 5	160–63	63.7	12.5	.19	19 0
W. Va. 13....	32 6	116	13.8	179–80	68 1	11.1	.14	15 7
Wyo. 4........	45 4	.... .	....	399	56 4	15.9	.07	24 0
Lab. 18........	43 4	142	19 4	....	......	.....	....	... ..
Wyo. 1............ .	43.8	165	15 1	63	54.9	11.2	.25	22 7
Tex. 4........	41 6	....	....	{291	59.9	6 9	.0	23 1
				{298	51.2	17.6	.0	35.2

[a] Volume in cubic centimeters from 10 grams in ten minutes, laboratory test.
[b] Pounds of dry coal per square foot of grate surface per hour.

W. Va. 11. Pocahontas bed, "smokeless" coal.
Pa. 19. Pittsburg bed, Westmoreland County.
Lab. 3. Pittsburg bed, Connellsville, Fayette County, Pa., similar to Pa. 19.
Ill. 19. No. 7 seam, Zeigler, Franklin County.
W. Va. 13. "No. 2 gas coal," Page, Fayette County.
Wyo. 4. Bituminous coal, Hanna, Carbon County.
Lab. 18. Bituminous coal, Diamondville, Uinta County, Wyo., somewhat similar to Wyo. 4.
Wyo. 1. Subbituminous, Sheridan district, 22 per cent moisture.
Tex. 4. Lignite, Wood County, 36 per cent moisture.
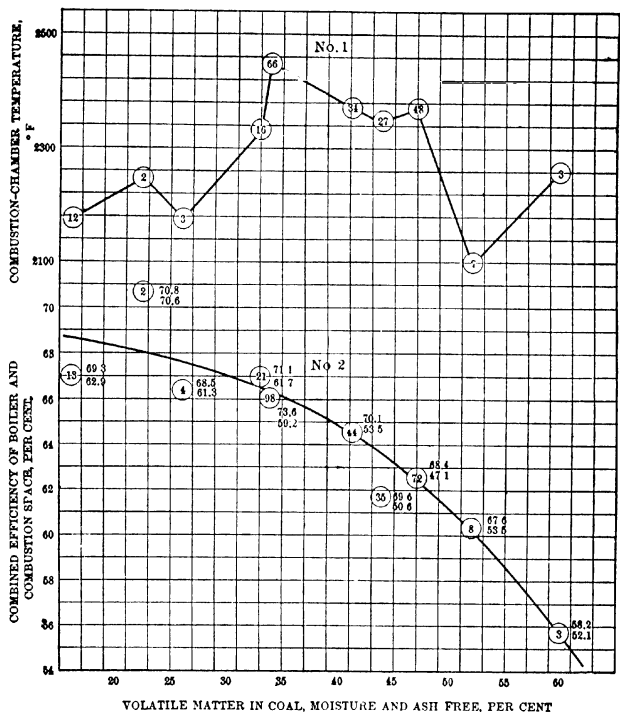
A. EFFECT OF VOLATILE IN COAL

Effect of the volatile matter in moisture- and ash-free coal on· Combustion-chamber temperature (No. 1); combined efficiency of boiler and combustion space (No. 2).

The chart in Figure A, by the *Bureau of Mines*, shows the efficiency obtainable with coals of different volatile content. The efficiency of the boiler and combustion space drops from 68 to 56% when the volatile rises from 20 to 60%. The figures in the circles give the number of tests averaged. Those outside the circles show the maximum and minimum efficiencies obtained. It will be noted that the minimum efficiency at each point drops off very rapidly as the volatile increases, while the highest efficiencies at each point are about the same for all groups, except that in which the volatile is highest. There is no particular difficulty in burning
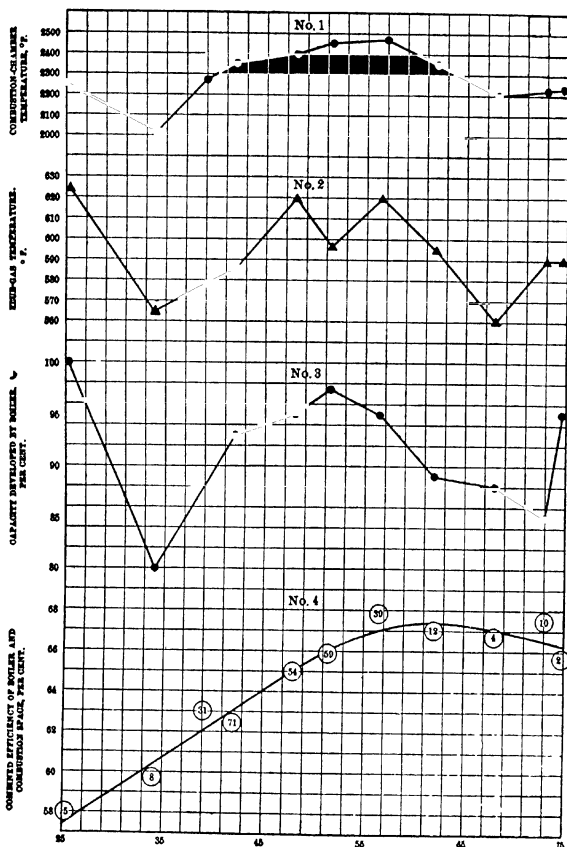
B. EFFECT OF FIXED CARBON ON BOILER PERFORMANCE

Relation between the percentage of fixed carbon in coal and: Combustion-chamber temperature (No. 1); flue-gas temperature (No. 2); capacity developed by boiler (No. 3); combined efficiency of boiler and combustion space (No. 4).

low volatile coal; consequently, the efficiencies in all such tests are very good. As the volatile becomes higher, the difficulty in burning the coal increases, and most tests come out with a low efficiency. The conclusion is that a great deal more care and skill are required to burn high volatile than low volatile coals.
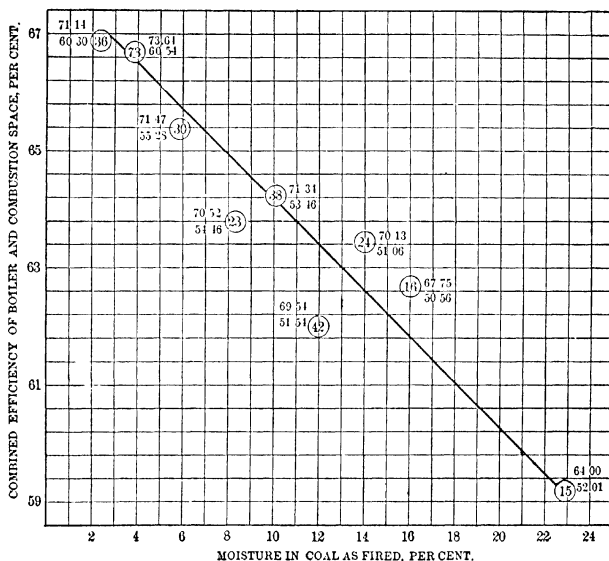
C. EFFECT OF MOISTURE IN COAL ON THE COMBINED EFFICIENCY OF BOILER AND COMBUSTION SPACE

Fig. B shows the efficiency obtainable with coals of different **fixed-carbon** content.

Fig. C shows that the combined efficiency of boiler and combustion space drops from 67% to 59% as the **moisture** in the fuel increases from 3 to 23%. The curve is plotted regardless of the nature of the fuels. Coals high in moisture are also high in ash; so that the effect is a combination of the moisture and ash effects.

Figure D shows that the overall efficiency drops from 65½ to 61¾% as the percentage of **ash** in the dry coal increases from 2 to 21%. This includes the grate; therefore the drop in efficiency is more marked than in Fig. E, opposite. The latter indicates a drop of only 1 5% in combined efficiency of boiler and combustion space when the ash increases from 5 to 17% High efficiencies can often be obtained with high ash coals, but the chances are much poorer than with low ash coals.
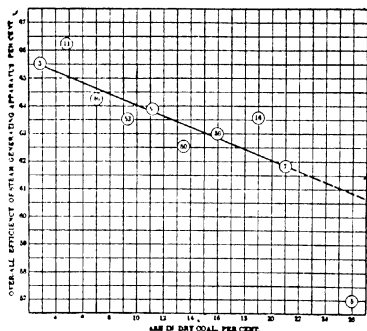
D   EFFECT OF ASH ON OVERALL EFFICIENCY

Per Cent of Boiler Rated Capacity Developed
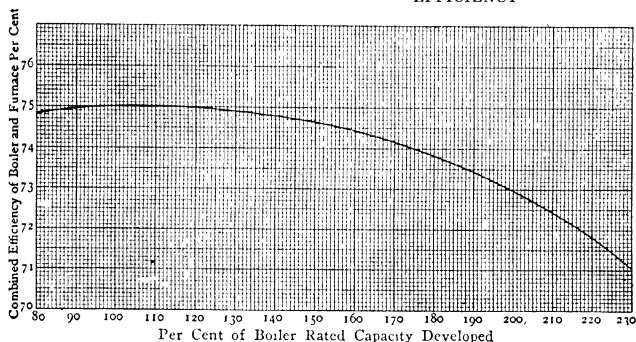
F.   APPROXIMATE VARIATION OF EFFICIENCY WITH CAPACITY UNDER TEST CONDITIONS

RELATIONS OF BOILER CAPACITY TO EFFICIENCY

Fig. F, from *Steam*, shows the relation of capacity to combined furnace and boiler efficiency. The maximum "true" boiler efficiency occurs at that load at which the sum of constant loss due to radiation plus the flue-gas loss bears a minimum ratio to the total heat supplied to the boiler. If the percentage of flue-gas loss is constant or decreasing, this point of maximum efficiency will occur at infinite load. If it is increasing, maximum true boiler efficiency will occur at a point where the rate of increase is equal to the total losses divided by the heat supplied. As maximum "true" boiler efficiency is always found at a comparatively light load, it is evident that the percentage of flue-gas losses actually increases with increasing load.
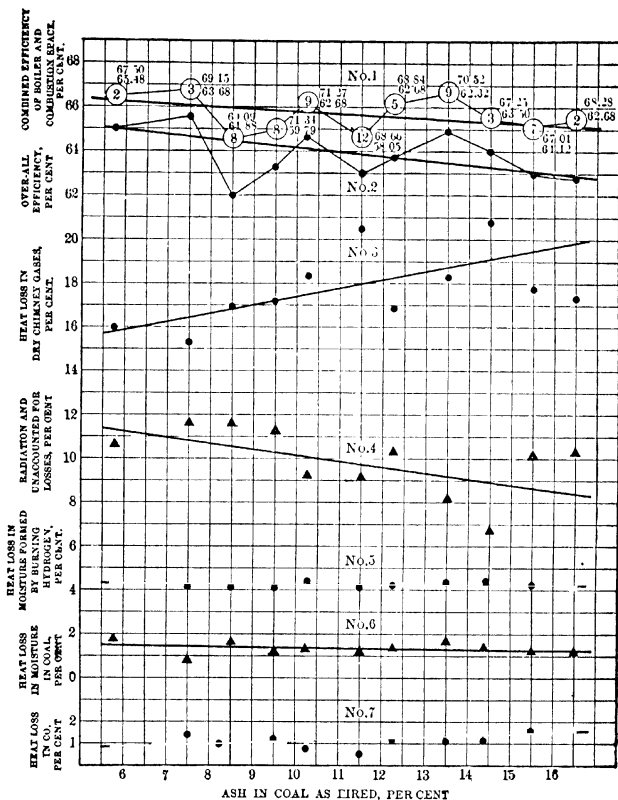
E. EFFECT OF ASH ON GENERAL BOILER PERFORMANCE

Relation of the percentage of ash in coal to
Combined efficiency of boiler and combustion space (No. 1)
Overall efficiency of steam generating apparatus (No 2)
Heat loss in dry chimney gases (No. 3)
Radiation and unaccounted-for losses (No 4)
Heat loss in moisture formed by burning hydrogen (No. 5).
Heat loss in moisture in coal (No. 6).
Heat loss in CO (No. 7).
The ordinates of curves 1, 2, 3, 4, 5, 6 and 7 are expressed as % of the heat of "combustible" ascending from the grate and therefore should add approximately to 100. Tests made with Illinois coals only.

In the actual boiler plant, furnace efficiency will, up to a certain point, increase with an increase in capacity. This is ordinarily at a greater rate than is the decrease in true boiler efficiency beyond the maximum just mentioned; therefore to a certain point, usually somewhat above the rated capacity, the combined boiler and furnace efficiency will increase with an increase in capacity. The load at which maximum overall efficiency occurs may be increased by using a larger combustion space and by providing for the absorption of more heat by radiation. See page 504.

Fig. G, by E. R. *Welles* and W. A. *Shoudy*, represents the characteristics of the 1500-HP. boilers at the U. S. Government Nitrate Plant at Muscle Shoals, Ala., similar in design to the 74th Street Station of the Interboro Rapid Transit Co. The boilers are Type M, No. 55, Stirling boilers, and furnish steam at the throttle at 275 lb. gage and 175° F. superheat. The furnaces are 27 ft. 6 in. wide, and are equipped with 15-retort underfeed stokers, and the boilers deliver 175% of rating at 600 lb. of coal per hr. per retort. Higher combustion rates are possible, but above 250% boiler rating the pressure drop through the setting becomes excessive. Twelve boilers are installed, but at the 175% rating, which has been adopted as standard, ten are sufficient to carry the normal load of 60,000 Kw.
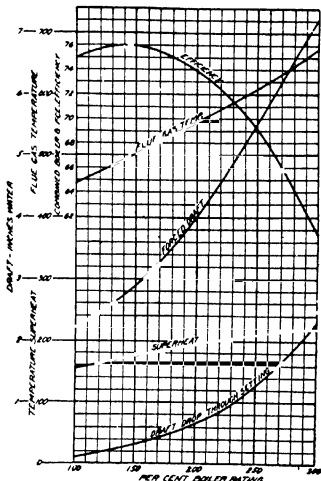
G. BOILER AND STOKER CHARACTERISTICS. 60 000 Kw. NITRATE PLANT—*Power Plant Engg.*

Joseph T. Foster gives Fig. H, showing the effect of combustion rate on boiler efficiency. The curves are based on results with a 140-HP. battery, except for buckwheat coal, for which the curve is the composite of tests on smaller boilers. The different fuels tested showed the best efficiency at a combustion rate of about 25 lb. per sq. ft. of grate per hour.

BOILER PLANT PROPORTIONING

The economy of the boiler plant as a whole depends upon the co-ordination of the several parts. R. J. S. *Pigott* describes the following method of handling this problem, as used in studying the 90,000-Kw. addition to the 74th Street Station of the Interboro Rapid Transit Co., New York, where the entire output is electrical energy from three 30,000-Kw. turbine-driven units. The Willans lines for three different vacuums and the water-rate curve for the main units, as guaranteed by the builder, are shown in Fig. A. The Willans line is a graph showing the relation between steam
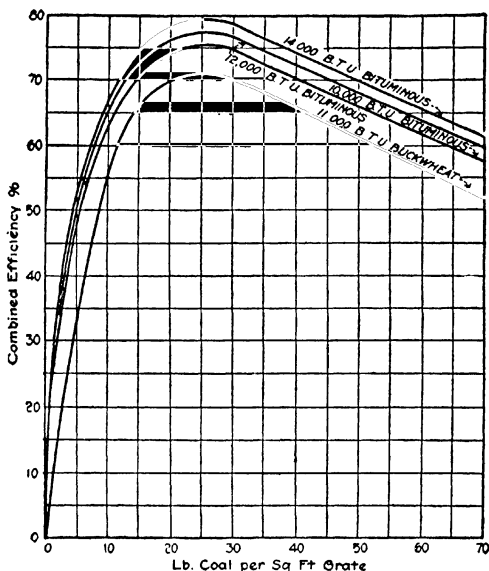
H. EFFECT OF COMBUSTION RATE ON EFFICIENCY

—*Power.*

consumption and output. For engines and turbines it is nearly a straight line, showing that steam consumption is made up of two parts, a constant for all loads and a part varying directly with the load. Similarly in Fig. B are shown the steam consumption and the *BTU* in the exhaust, for a 300-Kw. turbine-driven geared exciter set. Two exciters are so designed that in the event of the failure of one, the other could carry the entire load for a convenient length of time. Fig. C shows the steam consumption and the *BTU* in the exhaust of a 1000-gal. per min. turbine-driven boiler feed pump, on the basis of myriawatts of water capacity supplied (the myriawatt is equivalent to 34,150 *BTU* per hr., or to 1.02 boiler HP.). Fig. D similarly shows the steam consumption of forced draft fans and stokers for various amounts of air supplied to the fire; one unit serving a battery of two boilers consists of two fans driven by a single turbine. Curves in Fig. E show the relation between boiler output and cu. ft. of air required per min., draft pressure and brake HP., the latter being useful in considering electric drive for the fan and stoker. Fig. F is constructed from D and E, and shows the steam consumption and the heat in the exhaust of the forced draft blowers at various boiler outputs.
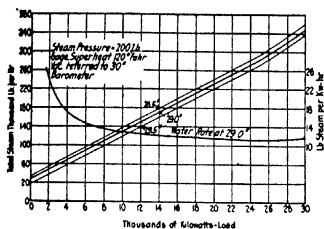
A. WILLANS LINES AND WATER RATE, 30,000 Kw. WESTINGHOUSE TURBINE UNIT
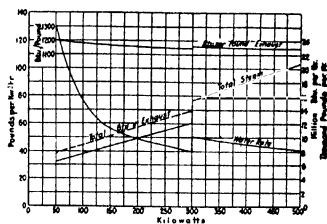
B. INPUT-OUTPUT LINE AND ECONOMY, 300 Kw. EXCITERS
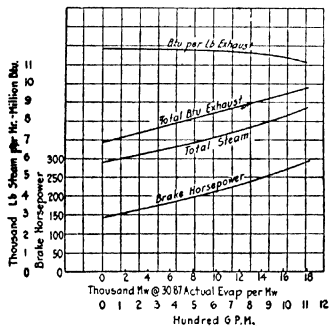
C. INPUT-OUTPUT LINES AND BRAKE HP., BOILER FEED PUMPS
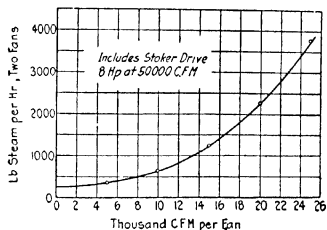
D. STEAM CONSUMPTION AND AIR DELIVERED, FORCED DRAFT BLOWERS
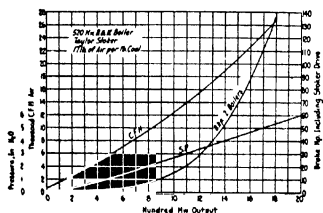
E. AIR, BLAST PRESSURE AND BRAKE HP., FORCED DRAFT FAN
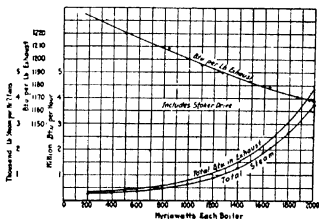
F. STEAM CONSUMPTION AND BOILER OUTPUT, FORCED DRAFT BLOWERS

—A.S.M.E.

With a fixed number of boilers already installed and paid for, the output efficiency curve, G, in connection with the performance of auxiliaries, is about all that is required in determining the best combination for handling different loads. Curve H shows the relation between boiler input in *BTU* and output in myriawatts, while Fig. I shows the steam required by auxiliaries, and the heat available in the auxiliary exhaust for various boiler gross outputs. Knowing the steam required by the main units, as shown in Fig. J, the total steam consumption, including engine room and boiler room auxiliaries, is obtained by adding the steam consumption of auxiliaries, as already given. It will be noticed that the most desirable point for cutting in a new unit is a little beyond the most efficient load of the unit already in operation. From I and J the total heat demand is obtained in Fig. K, in which the curves at the bottom show the heat units required in the feed-water heater, and the heat units available from the auxiliary exhaust per kilowatt of output.

G BOILER INPUT - OUTPUT AND EFFICIENCY, FROM TESTS
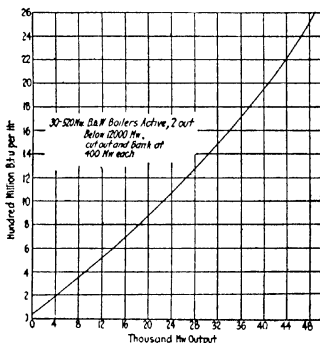
H BOILER ROOM INPUT-OUTPUT LINE
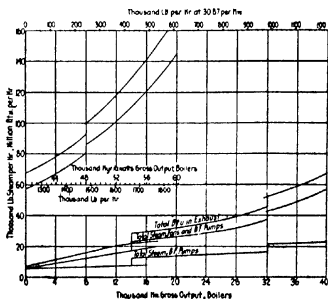
I. AUXILIARY INPUT-OUTPUT LINES

J. ENGINE ROOM STEAM DEMAND

—*A.S.M.E.*

With a fixed number installed **the number of boilers** which is most economical for carrying various **loads** can be determined from curves by *Pigott* for each boiler-stoker unit, giving the cost per Mw. hr. for maintenance, labor and coal, and the total cost per hr. per boiler at different loads, as in Figs. L and M. The total boiler-room cost per operated hour is shown for the entire range of load, with different numbers of boilers in operation, in Figs. N, O and P. By selecting the most efficient combinations to fit different parts of the load curve, the maximum efficiency is obtained, as shown in Fig. Q, where 30 boilers are more economical at light loads, and 37 at heavy loads. In a new plant, the greater number of boilers undoubtedly would not pay, as the fixed charges would more than offset the saving in cost of operation.

New Plants.—Where a new plant or the installation of additional equipment is under consideration, interest, d e p r e c i a t i o n, obsolescence, insurance, t a x e s, over-load capacity and efficiency must be studied in connection with the actual or expected load curve. A load of low load factor (the average daily load expressed as a percentage of the maximum or peak load) is most economically carried by equipment which can be forced to high ratings, although the efficiency at these ratings may not be high. A high load factor, on the other hand, may warrant the installation of a relatively large amount of heating surface, and possibly the building of high stacks, rather than the use of mechanical draft fans, which require an appreciable amount of steam for their operation. The selection of the amount of heating surface is aided by the construction of a diagram in which the abscissæ are total boiler surface and the ordinates are annual costs. For example, the ordinate of the curve for a feed pump (in this case a horizontal straight line, since it is not affected by the rate at which boiler surface is driven) would include interest, depreciation, attendance, heat consumed, etc. The curve for cost of boilers will be an upwardly sloping line. Fuel costs will be represented by a curve having a low spot at a point near the most efficient rate of driving for the average load. Cost of settings, buildings, etc., may show abrupt breaks at points where the number of boilers is changed, etc.

By adding together the ordinates of the separate factors, a total cost curve is obtained, the lowest point in which represents the amount of heating surface which will give the lowest annual cost of steam, in a plant
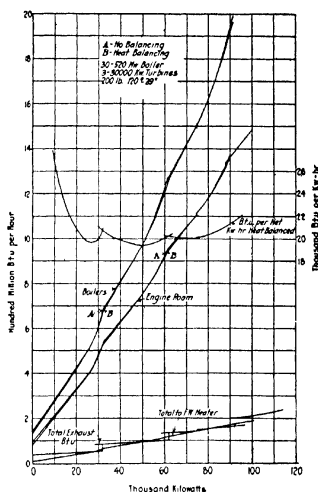
K. PLANT INPUT-OUTPUT LINES
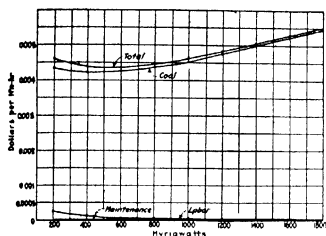
L. COST OF OPERATION PER Mw.-HOUR, 520 Mw., NEW BOILER

M. OPERATING COST PER HOUR, 520 Mw. NEW BOILER

N. VARIATION OF OPERATING COST, LIGHT LOAD
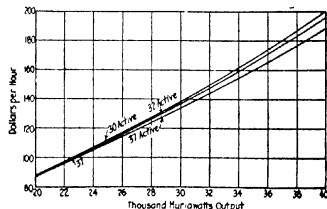
O. VARIATION OF OPERATING COST, MEDIUM LOAD

P. VARIATION OF OPERATING COST, HEAVY LOAD
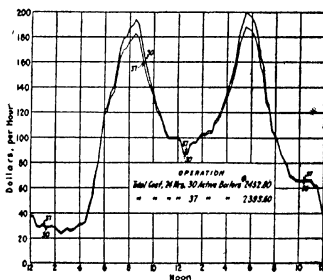
Q. HOURLY VARIATION OF BOILER ROOM OPERATING COST, ANTICI-PATED WINTER LOAD.—A.S.M.E.

having the assumed load curve, with apparatus of the costs and efficiencies assumed.

No factor should be overlooked. Consideration must be given to any possibility of abandonment of the plant after a limited term of years, or

the probability of expansion, the availability of improved apparatus or methods, the division of load between boilers, etc. The plant must be able to take care of the maximum peak with a margin to insure continuity of service.

There is a choice of several methods of carrying variable loads. In some plants certain boilers are operated continuously at 150 to 200% overload and banked boilers are cut in to take care of increased loads. Until recently this method has been generally followed in central station practice. In other plants a certain number of boilers are always in service. There are no banked fires, but peak loads are carried by forcing. A third method considers the plant divided into two parts, one taking care of a constant part of the load, this part being operated at maximum efficiency, the other part taking the variable load under either of the first two methods. It is, however, becoming more and more a settled principle, where the stoker equipment permits, to operate all boilers with the load evenly distributed. Boiler room economics demands that reserve capacity be placed in the coal-burning equipment. Spare boilers are an unquestionable necessity, although proper treatment of the boiler feed water supply reduces the number required. It may be found best to operate the spares at all times, cutting boilers out only for cleaning or repairs, thus reducing the load on each boiler and increasing the efficiency.

C. F. Hirshfield says that there is too often a tendency to strive for high efficiency without balancing the value thereof against the resulting increase of investment, complications, operating difficulties, and possibly maintenance charges. Furthermore, it is generally true that the designer is too optimistic regarding the useful life to be expected of a plant and also with respect to the capacity factor obtainable during the useful life. It is not at all uncommon to see a high-capacity-factor base-load plant relegated to second place at the end of five to seven years of useful life. As most such plants are built in installments, this means that only the units first purchased may be credited with the five to seven years of maximum usage, and that those installed near the end of the period must carry too heavy a charge against capital expenditures. Experience indicates that it is generally the wisest plan to design a plant for a lower thermal efficiency than initial assumptions and calculations might seem to justify.

The actual saving in operating cost made possible by the installation of the most highly efficient plant is comparatively small and frequently not large enough even to equal what may be called the factor of ignorance. Consideration of Fig. R will emphasize the point. Thus, assume West Virginia coal costing $5 per ton in the bunker. A plant that would produce a Kw. hr. with 1000 *BTU* less than another would save in fuel charges just less than 0.02 cent per Kw. hr. At 60% capacity factor and under the conditions assumed in this curve, this saving would be equivalent only to the increased fixed charges resulting from spending about $8 more per kw. of capacity. Frequently it would be impossible to secure this increase in efficiency with such a small additional investment. Therefore, a very high capacity factor over a long period or else a very low increment in cost is required to justify such an increased thermal performance. This is particularly true because the curves are based on fixed charges of 12%, which predicates a long, useful life. With stations and equipment changing as rapidly as they are, the fixed charges would be much higher.
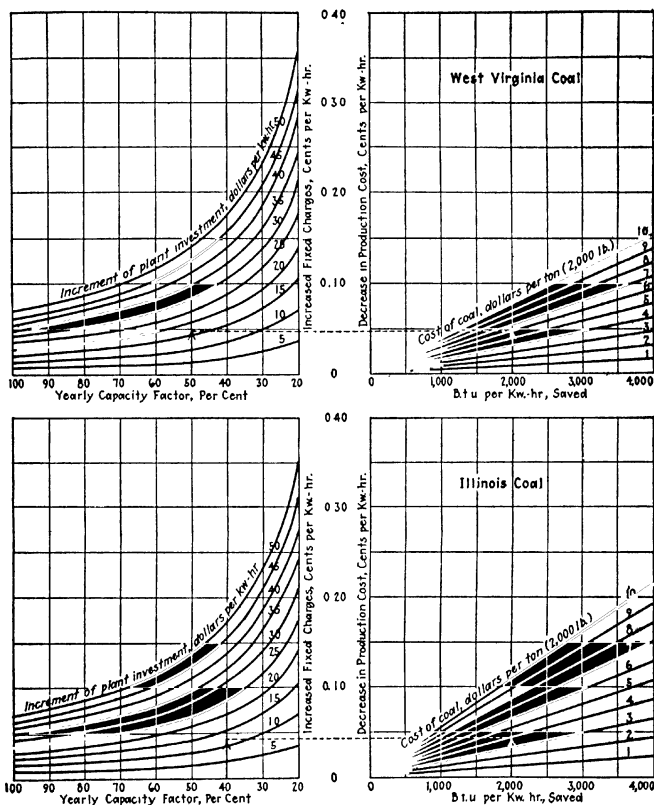
R. METHOD OF JUSTIFYING COST OF INCREASING EFFICIENCY .

Increment of plant investment which is just counter-balanced by decrease in cost of production by increasing thermal efficiency, taking into account cost of fuel and capacity factor. For example, if the design will permit a saving of 2000 *BTU* per Kw. hr. with $5 West Virginia coal, an increase in investment of about $17 per Kw. is just offset at 50% capacity factor of the station. Capital charges are assumed.— *Electrical World.*
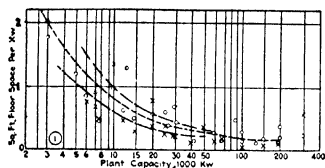
1. FLOOR SPACE PER KW.
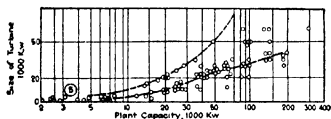
2. INDIVIDUAL TURBINE
CAPACITY
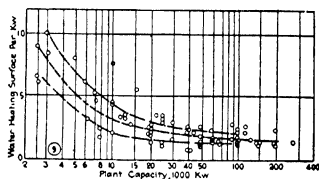
3. BOILER SURFACE PER KW.
—*Power*

John G. Fairchild gives, in Fig. 1, the floor space occupied by boiler and turbine rooms in a number of modern plants. The boiler-room points (circled) usually lie above those for the turbine room (crosses). The three lines are the mean and values 25% above and below the mean. The large per-kw. floor space of small plants is due not only to larger relative size of the units, but to the necessary clearances, such as aisles and room to remove tubes. Fig. 2 gives the size of individual turbines in relation to plant capacity, the upper line representing total capacity (one turbine per plant) and the lower one the mean size for the plants investigated. The one-turbine plants are mostly new plants, tied in with old plants, the plan being to enlarge the plant later. Fig. 3 gives the boiler heating surface per kw. capacity.
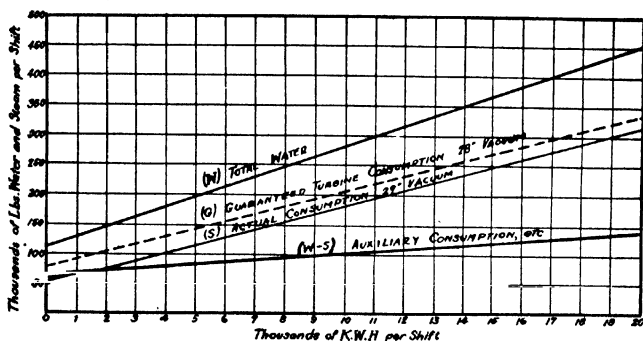
A. STEAM CONSUMPTION AND TOTAL FEED WATER—*London Engg.*

R. H. Parsons suggests the following graphic method of analyzing and comparing the **steam consumption** of engines and auxiliaries: The amount of feed water supplied and the steam consumed by the main turbine for definite periods are plotted against the corresponding power outputs. The specimen chart, Fig. A, does not represent a test, but was made from the routine log of a central station. It covers two weeks, and each eight-hour shift is represented by two dots, one for the total feed water pumped to the boiler during the period and one for the water passing through the main turbine, as shown by the condensate meter. Straight lines are then drawn to represent the averages. The equation for the upper line is $W = 110,000 + 17K$, in which W represents total water, and $K = $ Kw.-hr. output. $S = 48,000 + 13 35K$, where S is weight of steam used by turbine. $W - S = 62,000 + 3 65K$; the difference between W and S representing boiler blow-off, leakage, auxiliary steam consumption, condensation, etc. The dotted line represents the steam consumption at 28-in. vacuum, as guaranteed by the maker. For this particular period the vacuum averaged over 29 in., and the turbine steam rate was even less than guaranteed. The analysis brings out the fact, which will be found to be true in many plants, that the main unit is not deteriorating, and that the discrepancy between total water and the proper steam consumption is due to causes such as those just mentioned. The coal consumption per shift can be plotted in a similar manner. In the plant referred to, C, the weight of coal per shift, was found to be equal to $21,000 + 2.9K$. Eliminating K between this and the feed water equation gave $W = 5.86$ $C - 13,103$, or $C = 2235 + 0.17W$. This indicates that the limiting value of the evaporation was 5 86 lb. of water per lb. of coal, or that 2235 lb. of coal per shift would be required to keep up steam, if no water were evaporated.

In Fig. B, by *C. H. Delany*, covering a week's operation of a station in San Francisco, the average hourly oil consumption for each shift is plotted against the average hourly output for that shift, the equation of the mean line connecting the 21 points being $y = 120 + 4.1$ x, the "120" representing the hourly consumption of oil for zero load, that is, for keeping up steam, turning the turbine and operating the auxiliaries, keeping the plant in readiness to take on load at a moment's notice. This constant is larger if two turbines with their auxiliaries must be kept in operation than if only one is needed, and where a plant is operated as a standby to a hydroelectric system and is kept in readiness to pick up its full load instantly in case of trouble, it will have a higher value than where it is possible to shut down the turbines gradually, one after the other, as the load falls. The other constant determines the slope of the line and represents the additional amount of oil burned in proportion to the load, depending on the efficiency of the prime movers. He states that it is possible, with a fairly heavy load on the usual central-station plant, to secure without difficulty from 220 to 230 Kw. hr. per bbl. (4 55 to 4.35 bbl. per thousand Kw. hr.), whereas with the same plant it may be difficult to secure more than 150 Kw. hr. per bbl. (6.67 bbl. per thousand Kw. hr.) at light load.

Such a record represents a standard for the various average loads, which it should be possible to maintain except with runs where the load oscillates considerably above and below its average value for the run, as the uniform runs in general show better results. With a line drawn to represent the average or best past performance, runs falling below standard are quickly noted when plotted, although such a chart does not show the order in which entries are made nor whether conditions show a
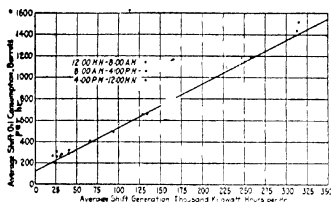
B. "PLANT CHARACTERISTIC" DIAGRAM FOR 8-HR. SHIFTS AT SAN FRANCISCO STATION
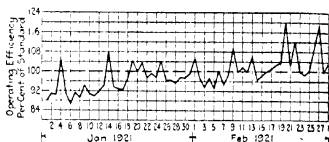
C. "OPERATING EFFICIENCY" CHART—*Iron Age.*

progressive improvement. "Operating efficiency" (percentage of standard attained for each run) can be plotted against time, as in Fig. C, which shows a gradual improvement as a result of attention to details brought about by this method of checking up efficiency. If in an 8-hr. shift, 313,000 Kw. hr. were generated and 1440 bbl. oil burned (217 Kw. hr. per bbl.) and 224 Kw. hr. per bbl. was the standard for such a load, the operating efficiency would be 97%. Charts similar to the plant-characteristic diagram can be plotted for steam generated against oil burned, or steam consumption against Kw. hr. generated, or auxiliary consumption against load, in order to separate boiler and engine-room performance. A single boiler will have a curved characteristic, while the characteristic for a large number of boilers will be approximately straight until the load exceeds the economical capacity of all the boilers in the plant, after which it will curve upward, but a curved line based on previous performance is just as satisfactory as a straight line for setting standards and calculating operating efficiency. It is just as easy to obtain 100% operating efficiency in a plant having old-fashioned turbines of poor design as in a plant having the most up-to-date machines, for the standard is based on the actual records of the plant itself.
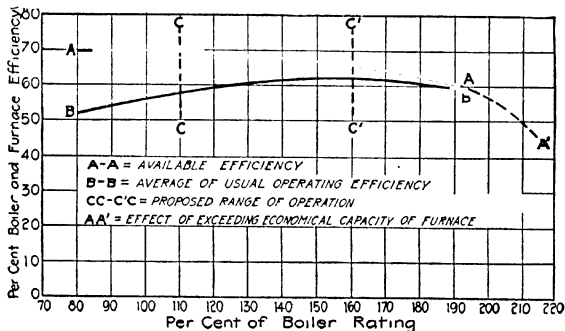
D. EFFECT OF DRIVING RATES ON COMBINED EFFICIENCY—*Power.*

Robert H. Kuss presents Fig. D to show the advantages of operating a small number of boilers at high rating. The maximum attainable efficiency at different rates of driving will follow a line such as *AA*, keeping up fairly well until a certain point, say 190%, after which it drops rapidly, as shown by the dotted line, due to insufficient draft or other conditions which make it uneconomical to operate at such very high rates. On the other hand, the efficiencies obtained in practice, represented by the line *BB*, are probably highest around 160%, because at that rate the constant effort to keep up steam forces the operatives to adjust the draft carefully, keep the fuel bed clean, etc , and the average practice approaches closely to the best practice, which itself is still comparatively high at 160%. For instance, with a battery of 400-HP. boilers, the most desirable rate of operation is at 160% of 400 HP , or 640 HP per boiler. If the average load is 2550 HP , four boilers would be ordinarily used. If the load increased, these four boilers would be forced one by one up to 190% of rating, if it decreased they would be allowed to drop to 110%. A load on either side of these limits would call for cutting out a boiler or putting more in service This forcing method means less work, less blowing down and soot cleaning, and more time to do work on the standby boilers.

E. C. M. Stahl describes a method used for determining the best order for cutting units in or out as the station load changes. With six machines having different water rates, there are 52 operating combinations and 720 possible sequences of arriving at these combinations For each sequence the total water rate can be plotted as a function of the increasing load. Fig. 1 shows the best and worst sequences as determined for one of the plants of the Brooklyn Edison Co. In this station, the rule is that, to provide against failure of the largest unit in operation, the other units in operation must be able to pick up the entire system load In Fig. 2 the curved line represents the actual station load, the horizontal solid lines for the various periods the maximum capacity of the units then in use, the dotted lines the most economical load for the units in question, and the dashed lines the available capacity upon the loss of the largest unit, the endeavor being to keep this latter line above the curve. At 2 P. M. the curve mounted above this line, and an additional unit was cut in.
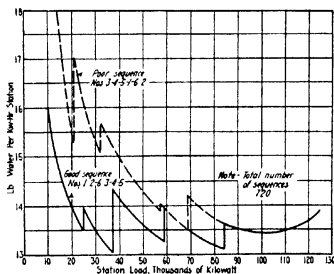
1. BEST AND WORSE SEQUENCE
IN STARTING UP
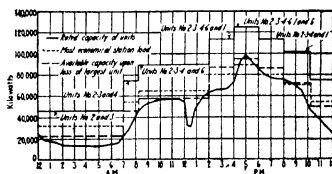
2. METHOD OF PREVENTING
LOSS OF LOAD—*Power.*

E. M. Gilbert describes a study made to determine the most economical type and size of boilers to be installed, the most economical feed water and flue gas temperatures and the economy to be obtained by the use of economizers in the *Susquehanna Station.* (See pp. 705, 706.) Fig. 1 shows the estimated total yearly plant operating cost, including the fixed charges, insofar as it is affected by the boilers and economizers, plotted against the total investment necessary for boilers and economizers of various sizes for various numbers of feed water heating stages, and indicates that three-stage heating is most economical with economizers where steam for feed heating is bled from the main turbine. Two stages was selected because of its greater simplicity. Without economizers four stages would be justifiable. Fig. 2 shows the estimated yearly operating cost, not including fixed charges, plotted against the total investment for boilers and economizers. Contour lines show the percentage return on "incremental investment"
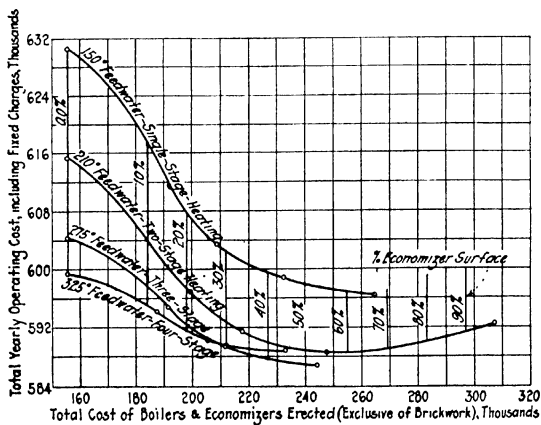
Fig. 1. STUDY OF BOILERS AND ECONOMIZERS TO DETERMINE THE MOST ECONOMICAL FEED WATER TEMPERATURE FOR THE FIRST 30,000-KW. UNIT OF A PLANT OF 180,000 KW. ULTIMATE CAPACITY. (Based on 159,000,000 kw-hr. per year, 13.500 *BTU* coal at $6 per ton, 1500-hp. boilers, and fixed charges at 17 per cent These curves show method only, the actual investment being considerably less than the figures shown.)

—*Mechanical Engineering.*

(defined as the return on the last ten per cent of surface installed) for the various degrees of feed water heating. Fig. 3 shows the efficiency of one size of boilers with various sizes of economizers plotted against the total cost of boilers and economizers. It indicates that where economizers are used a much less efficient and less expensive boiler is justified. Similar studies were made on all sizes and types of boilers and on all possible combinations of boilers and economizers. A study was also made of single-pass and two-pass surface condensers and of various circulating water velocities, considering the effect of vacuum on the operation of the main turbine and the average monthly circulating water temperatures, pumping costs, initial cost of condenser, tube maintenance, etc. Fig. 4 shows how yearly plant operating cost is affected by condenser size for different velocities of circulating water in a single-pass condenser.
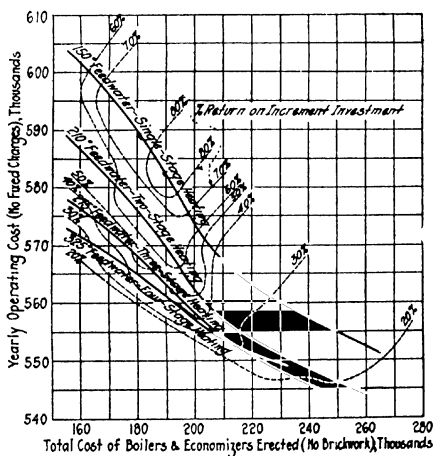
Fig. 2. ESTIMATED YEARLY OPERATING COST (FIXED CHARGES NOT INCLUDED) PLOTTED AGAINST TOTAL INVESTMENT FOR BOILERS AND ECONOMIZERS. (Based on 159,000,000 kw-hr. per year, 13,500 BTU coal at $6 per ton, 1500-hp. boilers, and fixed charges at 17 per cent. These curves show method only, the actual investment being considerably less than the figures shown.)

—*Mechanical Engineering.*
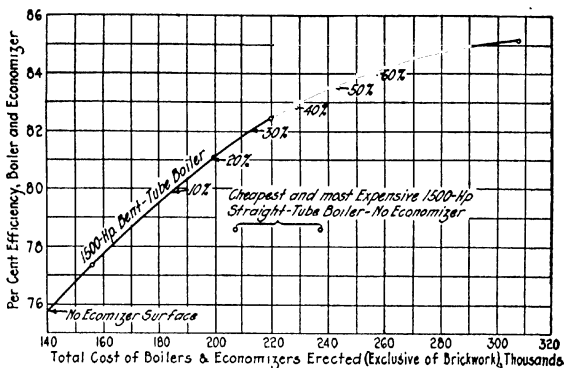
Fig. 3. EFFICIENCY OF BOILERS EQUIPPED WITH VARIOUS SIZES OF ECONOMIZERS PLOTTED AGAINST TOTAL COST OF BOILERS AND ECONOMIZERS (Based on 19,500,000 kw-hr. per year, 13,500 *BTU* coal at $6 per ton, 212° F. feed water temperature, and two-stage heating. Efficiencies based on stoker operation. Curve shows method only, the actual investment being considerably less than the figures given)

—Mechanical Engineering.
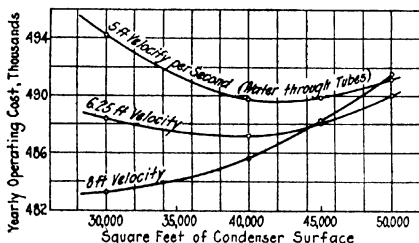
Fig. 4. YEARLY PLANT-OPERATING COST, INSOFAR AS AFFECTED BY CONDENSER, FOR VARIOUS SIZES OF SINGLE-PASS CONDENSERS WITH DIFFERENT VELOCITIES OF CIRCULATING WATER. (Based on 27,500-kw. load on a 30,000-kw. turbo-generator, 250,000 lb. of steam condensed per hour, and 159,000,000 kw-hr. per year generated.)

—Mechanical Engineering.
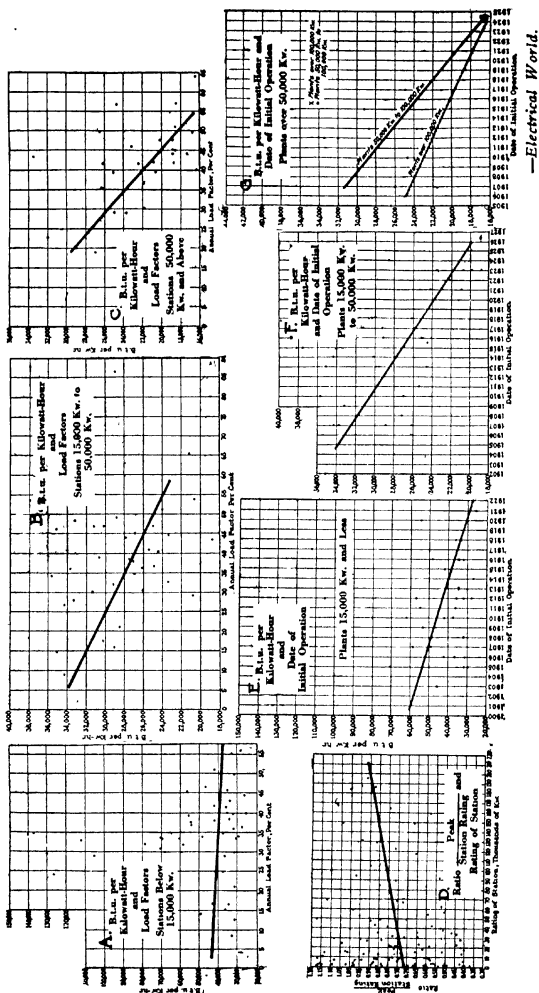
Vern E. Alden has analyzed data gathered by the *Electrical World* on the performance of 136 coal-burning stations for the calendar year 1924, covering 36% of the output of the steam-generating stations in the country, with capacities ranging from 187,500 Kw. down to 225 Kw. Charts A, B and C show performance (*BTU* per Kw. hr.) against annual load factor. Weighted average lines in B and C show a distinct trend toward better performance in connection with those stations operating on the higher annual load factor. This trend is due to two things:

1. In connection with all of the larger systems, the older stations, which are not capable of as good performance as some of the newer stations, are being assigned by the load dispatchers to carry the peaks of the system load, whereas the newer and more efficient stations are having assigned to them the job of carrying the base load.

2. The fact of low load factor, with the resulting frequent starting and stopping of the turbines and auxiliaries, the frequent banking of boilers, the operation of equipment at less than its most efficient load, accounts for a higher *BTU* per Kw.-hr. in connection with any particular station than would correspond to operation with a somewhat higher load factor under different conditions.

The first consideration seems more important as affecting the slope of the lines, and in connection with any particular station the effect of the change in load factor on station performance would not be nearly so marked as might be indicated from an inspection of B and C. Chart A, covering the performance of the smaller stations, does not show the same consistent trend. Chart D was plotted to find whether percentage of spare capacity allowed bore any relation to station capacity. A definite trend is indicated, approximately 26.5% of the station capacity being idle in stations of 10,000-Kw. capacity, corresponding to the time of the system peak, while in connection with 180,000-Kw. stations, only 11% of the capacity was idle at time of system peak. This is probably the effect of diversity entering in to allow of a more efficient use of each dollar of invested capital in connection with large steam-generating stations.

Charts E, F and G were plotted to determine whether the newer stations being built from year to year are showing progressively better performance. The convergence of the lines representing the weighted average performance of the stations falling in the different classifications is tangible evidence of the efforts of designing engineers toward better performance.

Chart I shows that for the smaller stations there is a somewhat consistent trend toward poorer station performance with higher ash content of coal, but chart J shows that in large stations it is possible to overcome handicaps and choose equipment specially suited to poor coal. Five stations using coal ranging from 10 to 16% ash showed station performances from 16,326 to 18,540 *BTU* per Kw-hr., constituting five of the most efficient stations in the country.

The costs of operating labor and superintendence and of maintenance bear about equal importance as elements entering into total operating costs, although neither is of the same magnitude as fuel costs. Charts L and M show a clear-cut trend toward lower maintenance costs in connection with those stations having higher plant use factors. There are two reasons for this trend:

1. A considerable amount of maintenance is necessary regardless of the number of Kw.-hr. generated by the station during the year. If this expense is spread over the large number of Kw.-hr. corresponding to a high use factor, the cost per Kw-hr. is decreased.
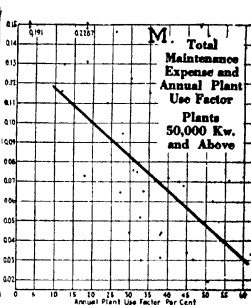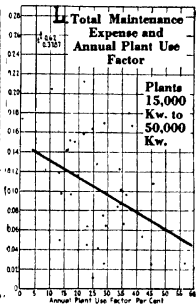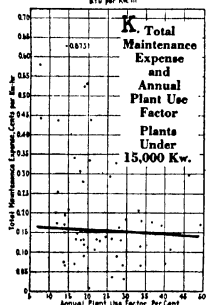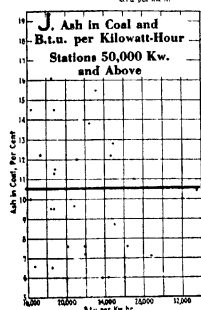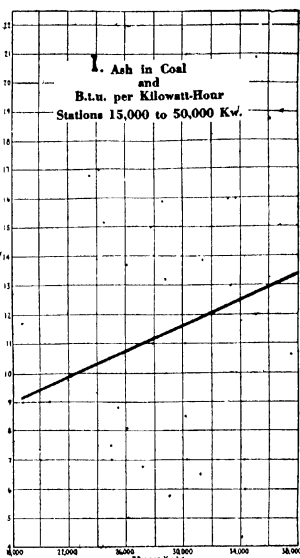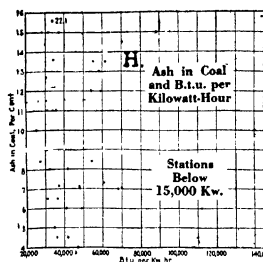
—Electrical World.

2. Frequent starting and stopping of turbines and long banking periods on boilers and stokers, which may be incident to low plant use factors, result in a more rapid deterioration of equipment and increased cost for maintenance.
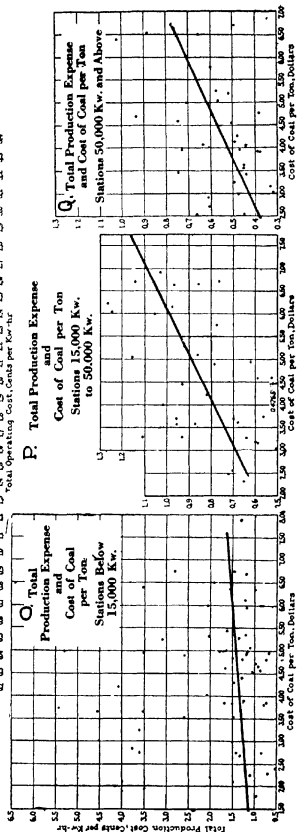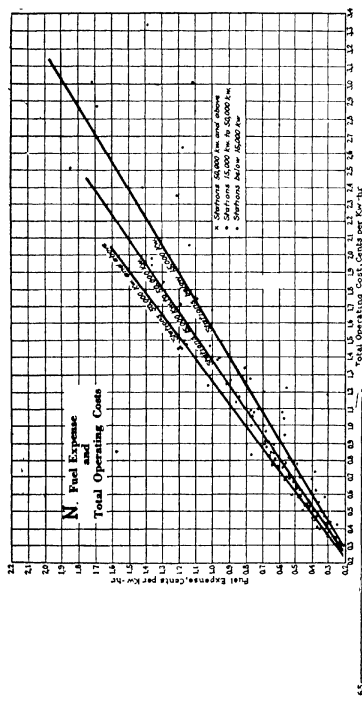
The increase in maintenance costs for the smaller stations is probably tied up with the use of smaller generating units and smaller boilers, together with the higher total investment per unit of installed capacity.

Chart N shows the ratio of fuel cost to total operating cost (fuel, wages and superintendence, water, lubrication and supplies, and miscellaneous). For a total operating cost of one cent per Kw.-hr., the fuel cost

is 78% of the total in the large plants, 72% for the medium plants, and 63% for the small plants, due to the decreased amount of operating labor incident to the use of larger generating units and boilers. Charts O, P and Q show the effect of cost of coal.

Charts R and S were drawn to show the analysis of operating costs in connection with eleven stations having a performance better than 20,000 *BTU* per Kw.-hr. The weighted average lines in S would tend to indicate that the lowest grand total of operating costs and maintenance corresponds to a station performance of approximately 17,800, but the low

T. Cost of Coal per Million B.t.u. and B.t.u. per Kilowatt-Hour

R. Operating Costs and B.t.u. per Kilowatt-Hour for Plants Under 20,000 B.t.u. per Kilowatt-Hour

Operating and Maintenance Costs and S. B.t.u. per Kilowatt-Hour for Plants Under 20,000 B.t.u. per Kilowatt-Hour
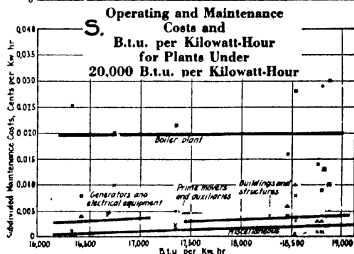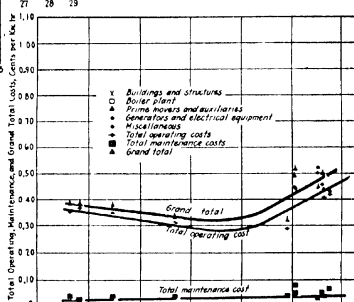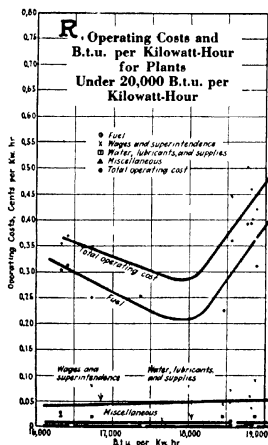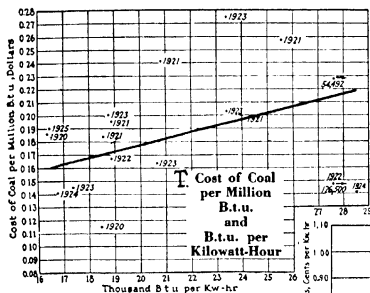
operating costs in connection with three stations having performances of 16,744, 17,361 and 18,460 *BTU* per Kw.-hr. are all accounted for by the extremely low cost per *BTU* of the coal burned in these stations. For the eleven stations referred to the average fuel cost is 72% of the average total operating cost, including maintenance, showing that stations are being so designed as to reduce the costs of operating labor and maintenance, as well as fuel. The boiler plant maintenance for the eleven stations is 54% of the total maintenance costs, and the present attention to reduction of furnace maintenance is seen to be justified.

Figure T is an investigation of the idea that the higher the cost of coal the more money the designing engineer is justified in putting into the station in order to get good operating performance. The weighted average line slants the wrong way, but this is accounted for to some extent by the good performance of the more recent stations. The four stations in connection with which the highest station performance has been obtained are all burning comparatively cheap coal, and it is a question whether extreme refinements in station design, in order to obtain the lowest possible fuel consumption, are justified, particularly in connection with stations located closely adjacent to ample supplies of cheap coal.

PERFORMANCE OF OIL-FIRED
BOILER ELECTRIC STATIONS
IN THE UNITED STATES

Btu per Kilowatt-hour

Total maintenance and operating cost
Total operating cost
Fuel cost

RATING, THOUSAND KILOWATTS

PERFORMANCE OF GAS-FIRED
BOILER ELECTRIC STATIONS
IN THE UNITED STATES

COST IN CENTS PER KILOWATT-HOUR

B.T.Us PER KILOWATT HOUR

THOUSAND B.T.Us

RATING, THOUSAND KILOWATTS
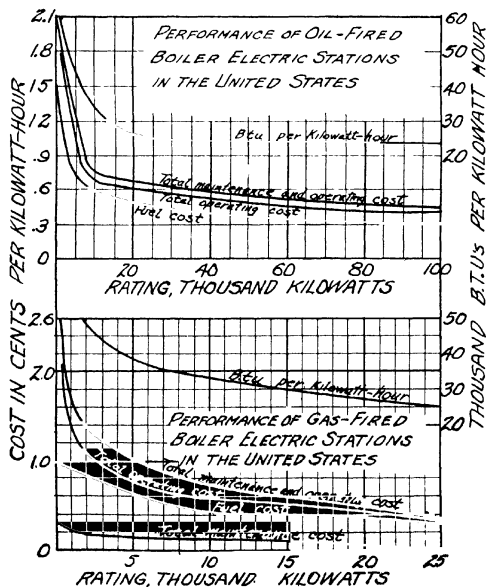
BOILER PLANT MANAGEMENT

The most perfect equipment and the most complete knowledge will not result in the highest economy unless they are consistently used in daily operation. As pointed out by *W. N. Polakov*, power plant management is often a haphazard undertaking, and 10 to 30% may be added to the operating cost if the securing of knowledge is left to the resourcefulness of individual employes, usually unaided with even the most elementary instruments for observation, seldom possessing the necessary time and authority for experimentation, and frequently unqualified for research work.

Planning.—He suggests that the function of securing the knowledge be vested with the plant's planning department, which should assume the permanent duty of carrying out investigations and researches. With every change of condition, such as a new grade of fuel, a different make of supplies, etc., the planning department will start an investigation to find out exactly how to cope with the circumstances.

The time and expense of testing by untrained persons is, as he remarks, a pure waste; oftentimes harm is done for the future by wrong conclusions derived. Tests that are made without keeping complete records of all conditions should not be run at all; only complete and continuous records are useful and dependable. Further, tests that do not take into consideration the human factor will fail of their object, since it may not be feasible for the men to duplicate the test conditions continuously. Test data should be carefully and exhaustively worked out, analyzed immediately, and checked several times by repeated tests to ascertain that results obtained once can be duplicated at will.

Polakov points out that the willingness and ability of the employe to do the right thing cannot be utilized unless it is definitely known *what the right thing is* in a given plant under given circumstances, but since the man himself, being employed to do things, seldom possesses the time and facilities to carry out all the necessary research work, it is a mistake to ask men to secure better results without teaching them how to do it, and without providing them with instruments showing the results obtained

Rewards.—Each man should be paid for doing his assigned part of the work in the proper manner, and not paid according to the final results, which are beyond the control of any one individual For example, if the boiler efficiency is lowered because of dirty heating surface, the loss should be charged against the man who has failed to clean it, and not against the fireman, who may have fired properly.

Each man is rewarded for the performance of his task. Failure to earn the reward or bonus is at once investigated; and if due to the fault of the individual, he receives his day-pay, but loses his bonus; if due to the fault of someone else, the individual is allowed his bonus, and the guilty person loses his. For example, if a new grade of coal should be substituted without proper instructions based on adequate research as to the best manner of burning it, the failure to obtain expected results would be chargeable to the planning department, not to the fire-room boss or to the fireman.

Polakov observes that the machinery of planning cannot be operated smoothly unless adequate means are provided for observing and checking

the results following the planning done in the past; and if the power plant, and particularly the boiler house, is not provided with all necessary instruments, there is no hope of operating it economically.

Organization.—An organization for carrying out this method of management may be outlined briefly as follows:

The chief executive of the power plant is the chief engineer All employes are responsible to him for the proper discharge of their duties, which include proper discipline and compliance with planning office orders.

The planning section is under the supervision of the superintendent, and the planning engineer in charge of the office is responsible to him. The functions of the planning office include order of work, instruction cards, records, time and cost keeping and personnel, including discipline. The planning office receives all requests, and co-operates with the chief engineer, the chief electrician, and the chief maintenance man The planning office reports to the superintendent of power on the progress of work and success of methods, and transmits to the office of the superintendent of power all records kept in the plant.

In the boiler room there is a gang boss, who takes charge of conditions for performing the work in each department. He sees that the necessary quantity of coal is delivered to the stokers in time, that water is fed to the boilers in the proper manner by the proper pumps, that each man has definite boilers assigned to him, and that all necessary firing tools, instruction cards, instruments, etc., are given to the men. A work boss is responsible for the performance of the work by each man His duty is to instruct the men how to work in accordance with the instructions prescribed on the instruction cards. He sees that the coal is fed into the furnace at the proper rate, that stoker and fan engines are running at the right speeds, that the depth of fuel is that required by the instruction cards, and that the draft is always according to the instructions for a given rate of driving. He instructs the firemen when to shake grates, and how to clean fires. In modern plants having automatic combustion control equipment for the regulation of stokers' fans and dampers, he makes the proper adjustments to secure the results desired.

As an example of the value of **instruments,** in boiler plant operation, *E. G. Bailey* mentions a plant using 150 to 250 tons of coal a week, which installed a full "boiler control board" at a cost of $2080 During the four months prior to its installation efforts to effect savings had resulted in economies of about $435.00 per month, while during the following four months, with the aid of the data supplied by the instruments, an increase of $710 00 in monthly savings was noted, representing a return of 400% per year on the investment. Instruments thus used operate not to "show up" the fireman, but to secure better results for him and the management. They become automatic calculating machines which give tangible results directly, without complicated figuring. The trend is now in favor of the recording type of instrument wherever possible, in spite of its higher cost, because of the permanent record which it furnishes, so that comparisons are no longer made on a memory basis.
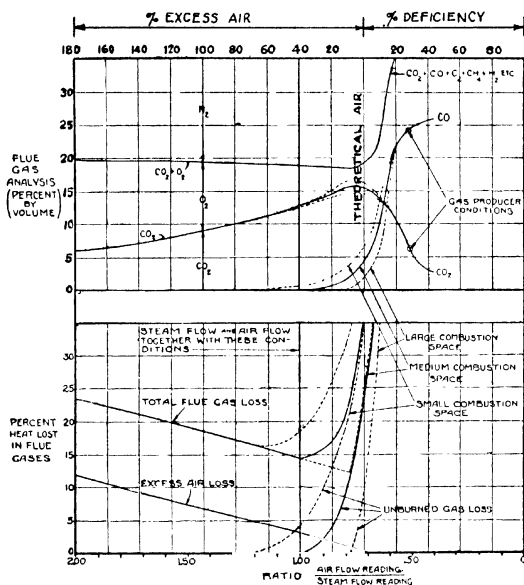
RELATION OF FLUE GAS COMPOSITION AND HEAT LOSS TO RATE
OF AIR AND STEAM FLOW—*Engrs Soc W. Pa.*

The above chart, by *E. G. Bailey*, is designed to interpret the results
of a combined steam and air flow meter, set to indicate a ratio of unity
between air-flow to furnace and steam-flow from boiler, when using 140%
of the air theoretically required for combustion, a condition which results
in minimum heat loss in the average plant. Greater ratios indicate surplus
excess air, reduced CO_2 and increased heat loss in the flue gases, while
ratios less than 1 indicate a dangerous approach to, or even a falling below,
the theoretical air supply, with the formation of CO and heat loss there-
from.

The data as to heat loss and probable CO content are equally appli-
cable to the results of the conventional CO_2 analysis. Generally speaking,
as the CO_2 rises from 6% to 13%, the excess air drops from 180% to
40%, and the flue-gas heat loss from 23% to 14%, which is the lowest
point on the curve. Further increase in CO_2 is usually accompanied by
CO, giving a sharp rise in the heat-loss line. See page 244.

MOLLIER DIAGRAM
FOR HIGH-PRESSURE STEAM

Example: 1 lb. saturated Steam at 300 lb. gage
expanded isentropically to 29 in. vacuum converts
1200-815 = 385 BTU into mechanical work.
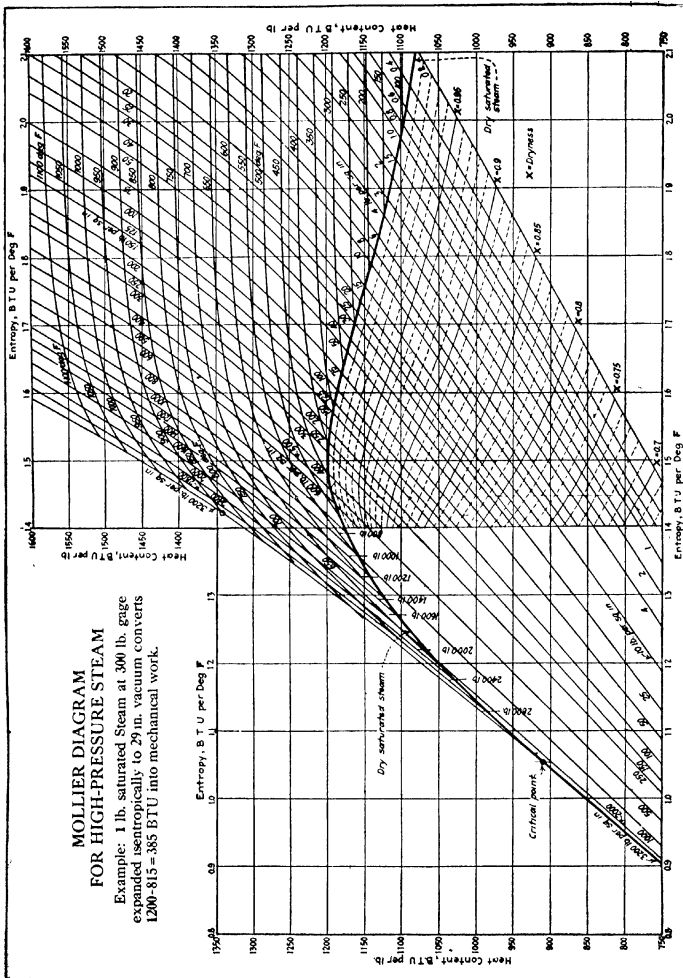
Sec. V —Feed Water Heating

and Conditioning

HEAT BALANCING

Remarkable improvements have lately been made in the efficiency of steam power plants through a more thorough study of "heat balancing," that is, of so choosing, proportioning and arranging auxiliary equipment that the plant processes will conform closely to the requirements of an efficient heat cycle, as defined by thermodynamic theory. It is well established that, where heat is converted into mechanical power,

(1) a reversible cycle gives the highest efficiency possible;

(2) the amount of work obtained from each unit of heat is the greater the wider the interval between the temperature at which heat is received and the temperature at which heat is rejected;

(3) no heat should be allowed to pass from a higher temperature to a lower temperature except in and by the process of doing work through expansion of the working fluid

Carnot pointed out that if a cycle more efficient than a reversible cycle could be found, an engine using the more efficient cycle could be applied to driving the reversible-cycle engine in the reverse order, so that more heat would be returned or "pumped up" to the source of heat by the reversible cycle than would be taken from it or "let down" by the more efficient cycle. If this were possible, the excess pumped up could be used in a third engine, which would thus produce power without any net consumption of heat, violating the principle of the conservation of energy.

As to what *Carnot* meant by a "reversible cycle," assume that steam from a boiler is used to drive an engine or turbine having no friction, radiation or conduction losses, and that at the end of expansion most of this steam is condensed by transmitting its heat to cooling water, while the remaining steam with the condensate is reheated by recompression, the amount of steam recompressed being so proportioned that at the end of the recompression it will be all condensed and the entire condensate will be at boiler temperature. Such a cycle would be "reversible" when operated in the order: (1) absorption of heat in the boiler, with expansion from water to steam, (2) further expansion of steam to condenser temperature, (3) partial compression and condensation at that temperature with rejection of heat to cooling water, and (4) compression with condensation and rise in temperature to boiler temperature and pressure. A certain amount of work would be delivered by this cycle, since on the whole the pressures are greater during expansion than during compression. Upon reversing the process, that is, (1) letting the temperature and pressure of the same amount of boiler water down with vaporization, (2) vaporizing the major part of the water by expansion under vacuum in the condenser, which has

now become a boiler absorbing heat from the circulating water, (3) recompressing the steam with a sufficient amount of water to keep the water saturated from condenser conditions to boiler conditions, and finally, (4) compressing and condensing the steam at boiler pressure, heat would be pumped back from the condenser level of temperature to the boiler level of temperature, consuming exactly the same amount of mechanical work that was produced by the cycle as first operated.

The ordinary *Rankine* cycle, in which steam is (1) generated in the boiler, (2) expanded from boiler pressure to condenser pressure, (3) entirely condensed in the latter, and then (4) pumped back cold into the boiler, is not a reversible cycle, for the reason that one part of the process, namely the heating of the boiler feed water by means of heat taken from the boiler at boiler temperature, involves the flow of heat by conduction from hot water or steam to cold water, and in order to reverse the cycle we would have to make the same heat flow back from cold water to hot steam. No means are known to thermodynamics of producing such reverse heat flow except by the application of work.

That the *Rankine* cycle is not so efficient as the reversible cycle follows from another of *Carnot's* postulates, namely that the quantity of work derived from a given quantity of heat in an engine depends upon, and is proportional to, the difference between the temperature at which heat is received by the working fluid and the temperature at which heat is rejected from the working fluid. In a reversible cycle, all of the heat is received at the highest temperature, that is, boiler temperature, and heat is rejected only at the lowest temperature, that is, condenser temperature. For the reversible cycle described, the greater the difference between the temperatures of reception and rejection, the greater will be the difference in pressures during expansion and recompression, and hence the greater the work done outside the cycle. In the *Rankine* cycle, however, some of the heat is received by the working fluid at temperatures all the way up from condenser temperature to boiler temperature, and this part of the heat received at the lower temperatures is not so effective in producing work as is the heat received at boiler temperature. That a small range of expansion does not give high efficiency is a familiar fact, but its direct bearing on the *Rankine* cycle is concealed in that with the *Rankine* cycle the feed water is raised to boiler temperature in the boiler. That there is a more efficient way of heating feed water will now be shown by a numerical example.

In expanding saturated steam from 300 lb. gage to ½ lb. absolute, that is, to a 29-in. vacuum, a perfect turbine using the Rankine cycle would convert slightly more than 34% of the heat of the steam into work, the remaining 66% being rejected to the condenser circulating water. The largest turbines now being built are expected to realize a little better than 80% of this ideal or theoretical result, while medium-sized machines, as used for "house generator" service, show efficiencies around 70% of that of the corresponding Rankine cycle.

The heating of cold condensate in the boiler by conduction or convection at temperatures progressively rising from condenser temperature to boiler temperature can be avoided by utilizing for heating the feed water steam which has done work by expansion to the temperature at which it is used for heating. Practically all of the heat of the steam so used is returned to the boiler except what is converted into work. In other words,

100% efficiency is realized, which is to be compared with the 34% converted from the steam which is exhausted to condenser.

A single open feed water heater operated at atmospheric pressure and receiving steam withdrawn from the corresponding stage of the turbine would, in the example of the perfect turbine, increase the efficiency of the cycle to 36½%. With a single feed water heater there is one certain feed temperature which results in the greatest improvement of overall efficiency, for, if the heater be operated at a higher temperature, although a larger amount of steam can then be extracted for feed heating, the steam will have been expanded through only a small range and will have developed only a small amount of power, while, on the other hand, if the feed water heater be operated at lower temperature, only a small amount of steam can be' utilized for feed heating, although this steam will have developed more work per pound. Assuming apparatus of commercial characteristics, 80° F. condensate temperature, 300-lb. initial steam pressure, and 200° superheat, with a single feed heater the maximum amount of work is obtained when the feed water is heated to between 210 and 250° F.

If the heating be done in an infinite series of heaters, each receiving the exhaust of an individual engine expanding steam from boiler pressure and temperature, with the condensate from each of the stage condensers transferred to the feed stream and returned with it to the boiler, the water will be heated continuously from the lowest condenser pressure to boiler pressure. All of the heat in the steam drawn from the boiler for the operation for these feed heaters will be returned to the boiler with the exception of the part converted into power by the engines in which the feed heating steam is expanded. In other words, the conversion of heat to power for this part of the equipment is 100% efficient, and therefore better than in the main engine or turbine, which, by assumption, converts into power only part of the heat which it receives, and discharges the larger part to the main condenser circulating water. Therefore, if the feed heating engines or turbines be considered as part of the main turbine, a better efficiency will necessarily be realized from the feed reheating cycle than if the main turbine were operated on the Rankine cycle, pure and simple.

Obviously the "regenerative" or feed reheating cycle just described becomes a perfectly reversible cycle if the stages of heating are infinitely numerous It is reversible as a whole because each part of it is reversible, that is, none of the steps involves a non-reversible operation, such as letting heat down in temperature by conduction or radiation.

In the example previously given, using saturated steam at 300 lb. gage and expanding to ½ lb absolute, the maximum efficiency obtainable is about 40%, and is in fact the same as the efficiency obtainable from the so-called perfect or Carnot cycle, in which all heat is received by the working fluid at the initial temperature T_1, and all heat is rejected at the final temperature T_2 The numerical value of this efficiency is $(T_1 - T_2)/T_1$, the temperatures being measured on the absolute scale, that is temperature Fahrenheit plus 461°.

An infinite number of condensers or heaters is not practicable, but usually one, two or three, or at the most four heaters are used. There is still some letting down in temperature by conduction in the individual heaters, as for example, where steam extracted from expansion at 250° F. may be used to heat water from 200° up to 250° F. The actual gain from stage heating is nevertheless considerable, one heater giving more than half

the total gain theoretically available from an infinite number of heaters. Two heaters do not gain twice as much as one heater, and as the number of heaters is increased a point is eventually reached where the gain does not justify the additional investment and complication. Figure *B*, p. 672, from the 1924 *Prime Movers Committee Report* of the *National Electric Light Assoc.*, shows the gain from one, two, three and four bleeder heaters in connection with a 28,000 Kw. turbine exhausting to a 29-in. vacuum. In a paper read by *Brown & Drewry* before the *American Society of Mechanical Engineers* the savings from one bleeder heater were calculated as 5.5%, from two heaters 7 3%, three heaters 8 3% and four heaters 8.65%, in net *BTU's* at the turbine throttle, giving the turbine credit for heat returned to the boiler in the feed water. See pages 651 and 665.

The 1925-26 *Prime Movers Committee* report states that in connection with newer stations designed for operation on the regenerative cycle, with steam for feed heating bled from the turbine at from two to four points, from 15 to 25% of the steam that enters the throttle is bled out before it reaches the last stage of the turbine. The Rankine cycle efficiency ratios at which the high pressure stages of modern large turbines operate are higher than for the low pressure stages which fall in the zone where the steam is wet. This helps to increase the overall efficiency for a turbine operated on the regenerative cycle. It has been thought that for turbines operating on the regenerative cycle there is a definite increase in the Rankine cycle efficiency ratio for the lower stages of the turbine, due to the withdrawal from the turbine of a considerable amount of moisture, together with steam bled for feed water heating. This has not been definitely proved.

Large steam turbines are now being built with four extraction nozzles located at stages such that the bleed temperatures are suitably spaced between 350° F. and condenser temperature. For example, a modern 35,000 Kw. turbine, of which a number have been built, is provided with bleeder outlets at points which at the load corresponding to maximum efficiency will supply steam for regenerative feed heating at 3½, 16, 50 and 120 lb. absolute. Bleeding from stages at higher pressure does not offer great inducements, both because of the higher pressure and temperatures which would have to be withstood by the bleeder heaters and because of the fact that steam bled from the higher pressures would have as yet done little work in the turbine. Higher steam pressures favor the use of more extraction points and increase the work to be done in the bleeder heaters To produce saturated steam at 500 lb. gage from condensate at 80° F. requires 1153 *BTU*, of which 399 are heat of the liquid and 754 are heat of vaporization.

The regenerative feed heating cycle can be carried out with steam driven auxiliaries as well as by bleeding from the main unit, the only difference being that auxiliaries as a rule will not return as much work from a given amount of steam as will the main unit. A perfect turbine using the Rankine cycle, receiving steam at 350 lb. gage and 250° F. superheat and exhausting to a 29-in. vacuum, would convert 36% of the heat into work, while a large actual turbine working between the same limits will deliver about 27% of the heat as work. Direct acting pumps might realize only 1⁄10 as much and velocity stage turbines probably not over ¼ as much. A pressure stage house turbine of 2,000 Kw., however, might show a net recovery of work from the steam used for feed water heating nearly as great as that realizable from the main turbine, especially if the comparison be based upon work

delivered at the driven machine. This is due to the fact that a house turbine driving a direct current generator can supply current to direct-current motor-driven auxiliaries without transformation, whereas the delivery of direct current from the main unit involves losses in transformers, rotary converters or motor generators, etc. If alternating-current motors be used the comparison is less favorable to the house turbine, but direct current is desirable for the operation of many auxiliaries, such as circulating pumps, mechanical draft fans, stokers, fuel feeders, cranes, hoists and other apparatus.

The advantages of bleeding steam from the main unit or using exhaust from auxiliaries are not confined to heating feed water, but such steam can advantageously be applied to any purpose for which it is hot enough, such as heating buildings, in processes, or for supplying hot water for washing, scouring, dyeing, general hot water service, etc. Where the entire exhaust can be utilized for heating purposes power is produced on a heat expenditure of only 2545 BTU per HP. per hour, as against 15,000 BTU or more required by the best turbines running condensing

The rule set forth in a preceding paragraph to the effect that the heat source should be drawn upon only at the highest temperature possible, that is, at boiler temperature, should not be taken to mean that heat at lower temperatures should not be utilized For example, the low temperature heat recoverable from the air which cools the generator windings, or from the oil which cools as well as lubricates the turbine and generator bearings, can advantageously be used for feed heating.

Similarly, heat can be recovered from chimney flue gases by means of an economizer, and, unless there are other uses for this heat, it can often be used advantageously for heating feed water In determining the amount of economizer surface, however, it is not sufficient merely to set off the value of the heat which the economizer can recover from the flue gases against the annual charges upon the economizer surface, including interest, upkeep and attendance. While the use of flue gas heat reduces the loss of heat through the chimney, it also removes in whole or in part the opportunity to improve the efficiency of the steam cycle through the use of partially expanded steam for heating feed water, and thus leads to waste of heat to condenser water. Analyses based upon conditions found in large plants show that the feed water should be heated to 180° or 220° F. by means of bled steam, even where flue gas economizers are used.

Chimney flue heat can be used in another way, namely, to heat air supplied to the furnace. The application of air heaters offers also certain incidental advantages, such as more complete and more rapid combustion, resulting in a higher percentage of CO_2 without waste of combustible gases to the chimney and less combustible in the ash, shorter flame, smaller firebox and higher furnace temperatures, so that more heat is transmitted directly to the boiler surfaces by radiation, leaving less to be absorbed from the gases by conduction or convection, etc. (See p. 549.)

Similarly, the rule that no heat should be degraded in temperature without doing work need not, for example, interfere with the use of high pressure make-up evaporators drawing heat from the system at a high temperature and returning it to the feed water at a temperature somewhat lower but still higher than the maximum bleed temperature. This does not in any way affect the efficiency of the cycle, since the heat so used

for the evaporation of make-up and then transmitted to the feed water would otherwise be absorbed by the feed water in the boiler and the degradation of heat would be the same in either case.

It is, however, detrimental to the efficiency of the cycle to withdraw steam from the turbine for use in an evaporator and to use the vapor generated in the evaporator for heating feed water in such a way as to replace bled steam. Suppose, for example, that steam for an evaporator is drawn from a turbine at a temperature of 250° and that the heat of this steam is returned to the feed water in the evaporator condenser at 150° F., at which point the turbine can also be bled. Obviously the opportunity has been lost to work this steam through 100°, or roughly over one-fifth of the entire working range. However, if the lowest turbine bleed point is at 250°, there is no loss in withdrawing steam for the evaporator at 250° and condensing the vapor from the evaporator in an open deaerating heater receiving water from the 150° bleed heater.

The degradation of the heat of bled steam in deaerators of the so-called flash type leads to a heat loss Assuming a flash temperature drop of 25° F., steam must be bled from the turbine at 215° F. in order that the deaerator may deliver water at 190° F., and the work which this steam could have done in the turbine between 215° and 190° is not realized. In other words, flashing the feed water detracts from the useful power output, the efficiency of the cycle is impaired and the heat loss to condenser per unit of output actually increased, although there may be no direct loss of heat from the deaerator itself This loss is avoided, however, if the water is deaerated at the temperature at which steam is withdrawn.

The efficiency or net gain from stage or regenerative feed heating systems is influenced by the type of heater used. Heat balance computations, which are complicated and laborious at best, are ordinarily made by the turbine builder, who bases his figures upon the use of extraction heaters of the closed or surface type. Closed heaters have, it is true, an important advantage in that a single pump can be used to force the water through a series of heaters. However it is not generally advisable to have the boiler feed pump draw directly from the condenser hot well, first because such conditions are not favorable for a fast running, high head pump, and second because there should be the equivalent of a surge tank somewhere in the system to take into account the fact that the mass of water contained in the boilers is different at different rates of steaming. The amount of storage required may vary from 5000 to 10,000 gallons in a 30,000-Kw. plant. The proper place for connecting in such water storage is on the discharge line from the hot well pump and preceding the boiler feed pump. If the water is forced through the extraction heaters by the hot well pump the heaters will not be called upon to withstand boiler pressure and can be of comparatively light and cheap construction. The head imposed upon the hot well pump will run from 10 to as much as 25 ft. per heater.

The most serious fault of the surface heater, however, is the inescapable drop in temperature accompanying transfer of heat from the steam to the water through the metal tube wall, such transfer of heat by conduction being detrimental to the efficiency of the cycle, as already explained. The attempt to avoid heat degradation by using large surface heaters runs into a large amount of surface. For example, with a water velocity of 4½ ft. through the heater tubes and a temperature rise of 80° F., each 1000 lb. of water heated per hour will require 6.4 sq.ft. of heating surface in order

to keep the terminal temperature difference down to 20° F., while to reduce it to 10° will require 8 8 sq ft., and to reduce to 5° will require 11.3 sq.ft. Even five degrees terminal temperature difference represents an appreciable increase in the net BTU required at the turbine throttle

Terminal difference can be entirely eliminated by the use of direct contact deaerating heaters. This type of heater is therefore justified economically, aside from the protection against corrosion which it gives to economizers, boilers, heating surfaces and piping, by eliminating oxygen from the water. With the direct contact heater, steam is not bled from the turbine until it has expanded and worked to the temperature to which the water is heated, and a thermometer placed in the water space of such a heater will indicate the same temperature as one in the steam space.

To illustrate the saving in net heat consumption resulting from replacing one of the closed heaters of a stage heating system by a direct contact heater, the figures in *Brown & Drewry's A.S M.E.* paper (p. 665) have been extended, recalculating the results with a direct contact heater in place of a closed heater in the second bleeder stage, see Table I. From line 40 it will be seen under Case I that the consumption per Kw per hr is 11,724 BTU with closed heaters in both heating stages and (Case III) 11,805 BTU if water is passed through a flash deaerator, while with a direct-contact deaerating heater replacing the second closed heater (Case II) it is only 11,677 BTU, a saving of 0 4% in total BTU over the closed heater and 1.1% over the flash deaerator. With an economizer installed the saving would be somewhat less, as may be seen in the added columns under "With economizers," where the saving over the closed heater is 0 25%. With three stages of bleed heating a direct contact heater in the third stage would save 40 BTU as compared with a closed heater, or 0 34%. Making all of the extraction heaters of the direct contact type would result in some further saving, but this is not practicable, as it would require additional pumps not otherwise needed. Direct contact heaters impose no friction head upon the hot well pump, as do surface heaters

The direct contact heater should be placed in the highest pressure stage, just ahead of the boiler feed pump, which can readily be done regardless of the bleed point if the deaerating heater is built with riveted steel plate construction Besides being an efficient heater and serving as a deaerator, the direct contact type of heater can also provide water storage, the entire volume between the overflow line and the pump supply opening at the bottom being available, while additional storage can be obtained by increasing the height, by adding an L-shaped extension to the bottom of the shell or by means of a separate tank equalized to the heater compartment. The steam condensed in a direct-contact heater is added to the boiler feed supply without the complication of traps or pumps and the heater also serves as a receiver for other apparatus, such as traps discharging live steam drips or the condensate from evaporator condensers, etc. The direct contact heater can act as the condenser for a makeup evaporator, affording the latter a greater temperature head than would a surface condenser, thereby materially increasing the capacity of the evaporator. If all or part of the boiler feed supply is makeup requiring softening, the direct contact heater can also take the form of a hot process softener.

In connecting an open heater, or in fact a closed heater or a heating system, directly to the bleeder nozzle of a turbine a steam check valve should be used to prevent back flow and consequent overspeeding under light load.

TABLE I. FEED WATER HEATING CYCLE WITH TWO EXTRACTION HEATERS

Based on method of *Brown* and *Drewry*

For 20,000-Kw. Turbine at "Most Economical" Load, 18,680 Kw., 350 lb. gage, 250° Superheat.

Case I. Using two closed heaters.
Case II. Using H.P. direct contact deaerator and L.P. closed heater.
Case III. Using H.P. open heater with separate flash deaerator and L.P. closed heater.

NON-EXTRACTING OPERATION

Item		
1	Output, Kw., given	18,680
2	Steam rate, Lb/Kw.Hr. given	9.53
3	Total steam, Lb./Hr, No 1 × No. 2	178,000
4	Generator efficiency, given	0.964
5	Brake HP. output, No 1 ÷ (No 4 × 0.746)	26,000
6	Total heat at throttle, BTU/Lb, from steam table	1356.5
7	Work done, BTU/Lb. (No 5 × 2545 ÷ No. 3) + 5% for friction	372
8	Total heat at exhaust, BTU/Lb, No 6 minus No. 7	984.5
9	Heat of liquid at hotwell. BTU/Lb, from steam table	47
10	Heat supplied by boiler. BTU/Lb, No. 6 minus No. 9	1309.5
11	Heat consumption, BTU/Kw.Hr., No. 2 × No. 10	12,480
12	Inlet pressure, Lb abs. (Throttle pres. abs. minus 5%). At other loads than M.E. proportional to M.E.	347

EXTRACTING OPERATION

Item		WITHOUT ECONOMIZERS						WITH ECONOMIZERS		
		CASE I		CASE II		CASE III		CASE I	CASE II	CASE III
		H.P.Htr.	L.P.Htr.	H.P.Htr.	L.P.Htr.	H.P.Htr.	L.P.Htr.			
13	Pressure at nozzle, Lb. abs. given for M.E. load value, at other loads proportional to No. 3	17.4	4.9	17.4	4.9	17.4	4.9			
14	Pressure at heater, Lb. abs. No. 13 minus 5% pipe drop and 2% extraction drop at H.P. nozzles 5% extraction drop at L.P. nozzles	16.2	4.4	16.2	4.4	16.2	4.4			
15	Saturation temperature at heater pressure, °F., from steam table	217	157	217	157	217	157			
16	Final feed water temperature No. 15 minus terminal difference (7°)	210	150	217	150	192	150			
17	Heat of liquid of No. 16	178	118	185	118	160	118			
18	Heat supplied by boiler. BTU/Lb. No. 6 minus No. 17 (for H.P. heater only)	1178.5		1171.5		1196.5		1073.4	1068.5	1085.5

EXTRACTING OPERATION

No.		WITHOUT ECONOMIZERS						WITH ECONOMIZERS		
		Case I		Case II		Case III		Case I	Case II	Case III
		H P Htr.	L.P.Htr.	H P Htr	L P.Htr.	H.P.Htr.	L.P Htr.			
19	Total heat at nozzle BTU/Lb from Mollier expansion lines .. BTU/Lb	1141	1079	1141	1079	1141	1079			
20	Total heat at exhaust . BTU/Lb No. 8	984 5	984 5	984 5	984 5	984.5	984 5			
21	$BTU/Lb.$ work lost in extracted steam No. 19 minus No. 20	156 5	94 5	156 5	94 5	156 5	94 5			
22	Kw.-Hr. work lost per 1000 Lb./Hr. of steam extracted. No. 21 × No. 4 × 1000/3416	44 2	26 7	44 2	26 7	44 2	26 7			
23	Total heat of steam at each heater BTU/Lb No 19 minus radiation losses	1141	1079	1141	1079	1141	1079			
24	Heat of liquid of steam at each heater. $BTU/Lb.$ No 17 + 7° terminal difference	185	125	185	125	185	125			
25	Heat available for heating feed water $BTU/Lb.$ No 23 minus No 24	956	954	956	954	956	954			
26	Final temperature of feed water ° F, No 16	210	150	217	150	192	150	315 1	320	303
27	Initial temperature of feed water ° F, for H P. = No 26 L P. for L P = temp. at 29 in vac	150	79	150	79	150	79			
28	Temperature rise of fled water ° F No 26 minus No 27	60	71	67	71	42	71			
29	Quantity of feed water Lb./Hr. H P = No 3 for Case I = No 3 — No 33 H P for Cases II and III L P = No 3 — (No 33 H P + No 33 L P) for all cases	178 000	155 926	166 342	154 820	170 692	158 868			
30	Heat transferred to feed water million BTU/Hr No 28 × No 29 — 10^6	10 68	11 071	11 145	10 992	7 169	11 280			
31	Heat flashed into heater by drained condensate mil $BTU/Hr.$ (No 28 for H P.) × (No. 33 for H P.) — 10^6		67							
32	Net heat supplied by extracted steam, mil. $BTU/Hr.$ No 30 minus No. 31.	10 68	10 401	11 145	10 992	7 169	11 280			
33	Weight of steam extracted Lb/Hr (No 32 × 10^6) ÷ No. 23	11,172	10 902	11 658	11 522	7 308	11,824			
34	Work lost in extracted steam Kw-Hr. (No. 33 ÷ 1000) × No 22	493 8	291.08	515.28	307.64	323.46	315 70			

EXTRACTING OPERATION

No.		WITHOUT ECONOMIZERS						WITH ECONOMIZERS		
		Case I		Case II		Case III		Case I	Case II	Case III
		H.P Htr	L P Htr	H P Htr	L.P.Htr.	H P Htr	L.P.Htr.			
35	Total decrease in output Kw. Hr. sum of No. 34 for all heaters	784 88		822 92		639.16				
36	Kw. output extracting, No. 1 minus No. 35	17 895		17 857		18 041				
37	% decrease in output when extracting, No. 35 ÷ No. 1	4 18		4 45		3 42				
38	Steam rate, Lb./Kw Hr (for exact frac loads of units proportioned for extraction) No 3 minus No 36	9 948		9 968		9 866		9 948	9 968	9 866
39	Steam rate, Lb./Kw-Hr (for non-proportioned units from curve of No 38 vs No 36 at exact fract loads)	9 948		9 968		9 866				
40	Heat consumption BTU/Kw-Hr 18 × No 38 if extraction unit, 18 × No 39 if not proportioned	11 724		11 677		11 805		10 677	10 650	10 710
41	Weight extracted fractional loads each heater, Lb./Hr., No 33 + % in No 37	11 639	11 358	12 177	12 035	7 568	12 228			
42	Weight extracted, fractional loads all heaters, Lb./Hr., sum of No 41	22 997		24 212		19 796				
43	Total steam, Lb./Hr., No 3 + No 37	185 440		185 921		184 088				
44	Amount of water evaporated, Lb./Hr (No. 43)		185 440		185 921		184 088	185 440	185 921	184 088
45	Coal burned Lb./Hr. (At 74% boiler ef., 13,500 BTU coal)							19 940	19 860	20 000
46	Weight of flue gas, Lb./Hr (15 1 × No. 45)							301 100	299 886	302 000
47	Temperature of flue gas from boiler (assumed)	600		600		600		600	600	600
48	Feed water temperature to economizer (No. 26)							210	217	192
49	Temperature rise in economizer (Gebhardt, p. 611, 5th ed.)							105.1	103	11t
50	Final flue gas temperature (Gebhardt, p 613, 5th ed.)	600		600		600		330	335	318
51	Water temperature to boilers, No. 26 or (No. 48 + No. 49)	210		217		192		315 1	320	303

C. F. Hirshfeld and *F. O. Ellenwood* report a study of the relative thermal and investment costs for operating central stations by the six different **ideal cycles** illustrated.

In the *Rankine* cycle, *A*, steam is formed at constant pressure, and is considered to pass without loss by throttling or radiation to the turbine, in which adiabatic expansion, *cd*, takes place, followed by condensation at constant pressure as shown by *da*. This cycle is simple and in common use, but has less possibilities as regards thermal economy than some others. In the *Reheating* cycle, *B*, steam expands adiabatically from *c* to *d* and then is reheated at constant pressure from *d* to *e*, after which a second adiabatic expansion takes place from *e* to *f*. The reheating apparatus involves physical complications. The *Isothermal-Superheating* cycle, *C*, involving isothermal expansion of superheated steam, *cd*, shows a maximum which might be approached by an infinite number of constant-pressure reheating devices. In the *Regenerative* cycle, *D*, steam is bled from the turbine at a number of stages to feedwater heaters. Without bleeding, adiabatic expansion would continue from *d* to *e*, but with it successive portions of the steam are withdrawn from the turbine and condensed, while the remainder continues isentropic expansion in the turbine. If at each temperature the condensed and unbled steam be considered as mixed together, the resultant state is that shown by *de*, parallel (for saturated steam) to the liquid line *fa*, for the entire weight of steam, the area *abcde* representing the energy available from this steam. Note increase in feed temperatures with high pressures. In the *Reheating-Regenerative* cycle, *E*, the area *abcdegh* represents the available energy in *BTU* per lb of throttle steam. This cycle implies considerable complication, but its possible advantages may apparently justify the building of a plant to operate with this ideal. In the *Isothermal-Regenerative* cycle, *F*, the regenerative portion is as in the last two, but the saturation temperature at which bleeding begins is determined by the amount of isothermal expansion permitted in the turbine, the length of *cd* determining the temperature at *e* and hence at *f*. It indicates the limiting possibilities of cycle *E* with infinite reheaters, so that the isothermal expansion in superheated region is approached by *cd*.

The efficiency of any ideal cycle is the ratio of available energy, or energy convertible into work, to the heat supplied during the entire cycle. For the six cycles, it is as follows, neglecting feed pump work, which was found to be justifiable.

$$[A]\quad \frac{H_c - H_d}{H_c - q_a}$$

$$[C]\quad \frac{H_c - H_f + (t_d - t_e)\,(E_d - E_e)}{H_c - q_a + T_d\,(E_d - E_e)}$$

$$[B]\quad \frac{H_c - H_d + H_e - H_f}{H_c - H_d + H_e - q_a}$$

$$[D]\quad \frac{H_c - q_f - T_e\,(E_d - E_f)}{H_c - q_f}$$

$$[E]\quad \frac{H_c - H_d + H_e - H_g + (t_g - t_h)\,(E_g - E_f)}{H_c - q_f + H_e - H_d}$$

$$[F]\quad \frac{H_c - H_h + (t_d - t_e)\,(E_d - E_e) + (t_f - t_g)\,(E_e - E_f)}{H_c - q_f + T_e\,(E_d - E_e)}$$

where *H* is specific total heat of steam and *q* specific total heat of liquid, both in *BTU* per lb. for any state indicated by the subscript, *T* is abs. temperature and *t* ordinary temperature, ° F., *E* is specific entropy.
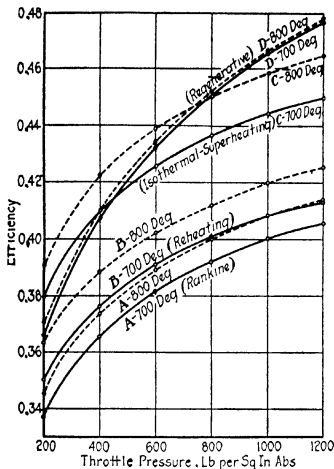
G. COMPARATIVE MAXIMUM
EFFICIENCIES

H. EFFECT OF CYCLE ON VOLUM.
OF EXHAUST

Throttle temperatures 700° and 800° F. Back pressure 1 in. *Hg.* abs.
—*Hirshfeld & Ellenwood (A.S.M.E.)*

From Fig. *G,* regenerative cycle *D* deserves first place as far as efficiencies on the ideal basis are concerned, especially for high throttle pressure. This cycle was also found to have a larger amount of energy available for work in the ideal turbine per unit volume of exhaust steam, Fig. *H,* this being a partial measure of the relative sizes and costs of the turbines required to give the same power with different cycles. For each cycle there is a marked increase in efficiency and in energy available per cu. ft. of exhaust, with increase in throttle pressure, although this is less marked in the simple Rankine cycle. The extra apparatus for the regenerative cycle would seem to be simple enough to justify the expense in many cases. From these ideal-cycle efficiencies, and from probable turbo-generator efficiencies, Fig. *J* (gross generator output equals product), complete plant studies were made, based on electric auxiliaries. It was found that increasing the pressure from 200 to 1200 lb. abs. increases by about 30% for any particular cycle the cost of all equipment affected by the steam pressure (condensers, auxiliaries to operate boiler at 300% rating, heating surfaces, piping system, turbo-generators, air heater at $1.60 per sq. ft., flues, etc.). From Fig. *K,* which includes cost of land, canals, railroads, foundations, buildings, coal handling, and miscellaneous mechanical and electrical equipment, it appears that the 1200-lb. plant would cost only about **14% more than the 200-lb. one to operate on the same cycle. The Rankine cycle plant is appreciably lower in first cost than any of the others, and cycle *E* the highest. Some plants will have a larger portion of the total plant cost dependent upon pressure than was used in this study.**

A. RANKINE   B. REHEATING   C. ISOTHERMAL-REHEATING

D. REGENERATIVE   E. REHEATING-REGENERATIVE   F. ISOTHERMAL-REGENERATIVE
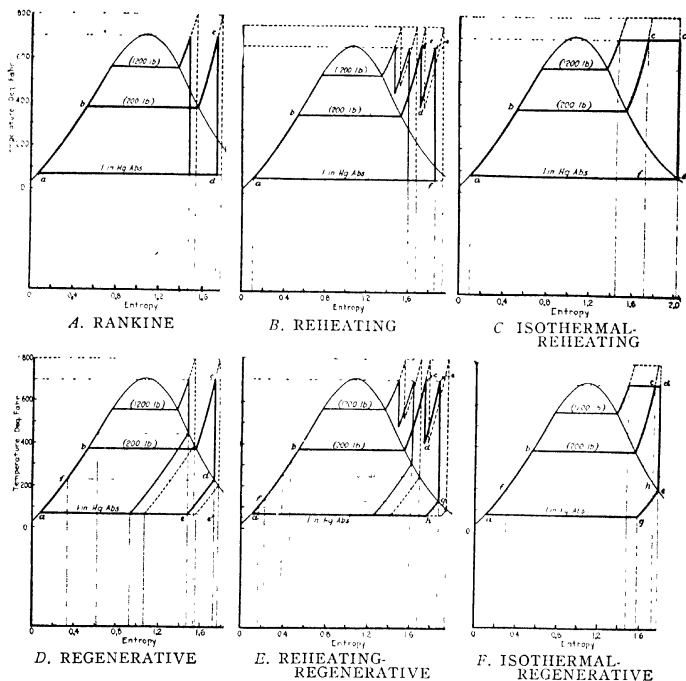
IDEAL CYCLES CONSIDERED

Throttle pressures 1200 and 200 lb. abs., temperatures 700° F. (solid) and 800° F. (dotted), exhaust pressure 1 in. Hg abs. Constant pressure process abc common to all cycles.   —Hnshfeld & Ellenwood (A S M.E.)

Fig. L gives estimated coal consumptions. For pressures under 400 lb. abs., the Rankine cycle requires about 5% more fuel than any of the others, and at higher pressures the regenerative principle saves fuel. Cycles D and E at 1200 lb. only require about 80% as much fuel as the Rankine cycle at 200 lb.

Considering total cost of energy at switchboard (fixed charges, operation, maintenance and fuel cost), it appears that with coal at $5 per ton the regenerative cycle is superior to the others for all pressures, but compared with the reheating-regenerative this superiority is very small for pressures above 800 lb. abs. Pressures above 600 lb. are not so attractive as sometimes believed, especially for capacity factors under 100%. With coal at $8 and with base-load conditions the best pressure would appear to
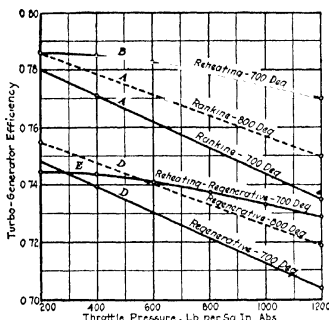
J. PROBABLE TURBO-GENERATOR
EFFICIENCIES

Referred to four ideal cycles 30,000-
Kw. units, exhaust pressure 1 in *Hg* abs.
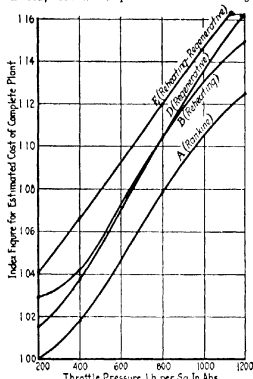
K. STATION COST
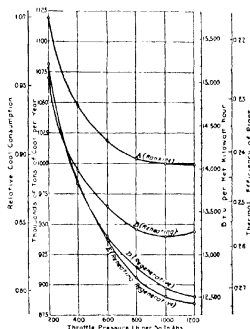
I. EFFECT OF STEAM PRESSURE
AND CYCLE ON COAL CONSUMPTION

200,000-Kw. plant, capacity factor 100%,
boiler efficiency 84% 700° F throttle
temperature, exhaust 1 in Hg abs, coal
12,300 *BTU* per lb
—*Hirshfeld & Ellenwood (A S M E.)*

be near 1000 lb. abs, and for these conditions the regenerative and
reheating-regenerative are the best cycles, except for pressures less than
400 lb. abs.

While calculations were given for 700° and 800° F. steam temperature,
the authors stated that the then safest upper limit (1923) was probably
between 700° and 750° F. Development of high-pressure systems calls
either for cycles involving regenerative heating only or those involving
reheating with or without regeneration. The regenerative cycle is simpler,
being hardly more complicated than the Rankine, and the performance here
estimated for such plants can probably be further improved by using

turbines designed to separate and remove water formed during expansion. Economizers become of less value with the regenerative cycle as the initial steam pressure is increased, with increasing temperature of feedwater from the regenerative heaters, which suggests the use of air heaters raising the temperature from 100° to 200° F. above normal temperature if full conservation of waste heat is to be made.

A. G. Christie and Douglas C. Turnbull, Jr., have applied the methods of Hirshfeld and Ellenwood to a study of plants operating at moderate pressures, but with high temperatures. In Fig. M, the solid lines represent the net BTU consumption per Kw. hr., for boiler pressure 415 lb. abs., initial temperature varying from 700° to 1000° F, while the dotted lines are for initial temperature 700° F. throughout, boiler pressure varying from 200 lb. to 1200 lb. abs. For the Rankine cycle, the 400 lb. abs. plant, with steam 825° F. or higher, is more efficient than even the 1200 lb. 700° plant on this cycle, while the 400 lb. 1000° plant on the regenerative cycle equals the performance of the 1200 lb. 700° station   If the high temperature plants had been figured for bleeding in the superheat region to give the same feed water temperature of 252° F. as in the 400 lb. 700° plant, there would have been a further decrease in BTU per Kw. hr. and the curves would have favored high superheat still more. The curves indicate that the 600 lb 700° plant has the same performance as the 400 lb. 850°. Steam temperatures of 850° F. are said to have already been used in Europe on steam turbines. The gains from superheat compare so favorably with those obtained in plants using high pressures that further development of materials for high steam temperatures seems warranted   Boilers for 415 lb. abs. can be of standard construction, purchased on a competitive basis, and the only parts requiring special construction for high temperatures are the superheater and its fittings, steam piping, valves, drips, etc., and the high pressure section of the turbine. The authors state that while certain parts have been subject to 1000° F. in the oil industry, 750° F. has been the limit in central stations. New alloys such as Everbrite metal are being developed for use at 1000° F.
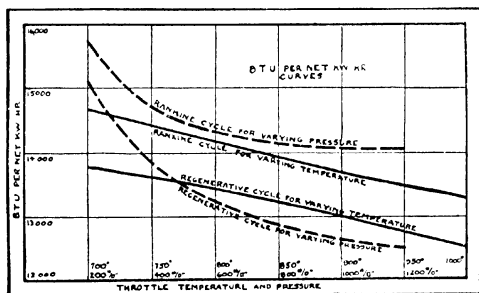
M.   ECONOMY AT 415 LB. ABS. WITH VARYING HIGH
       TEMPERATURE VS. 700° F. AND VARYING HIGH
       PRESSURES.—Christie & Turnbull (Prime Movers Report)
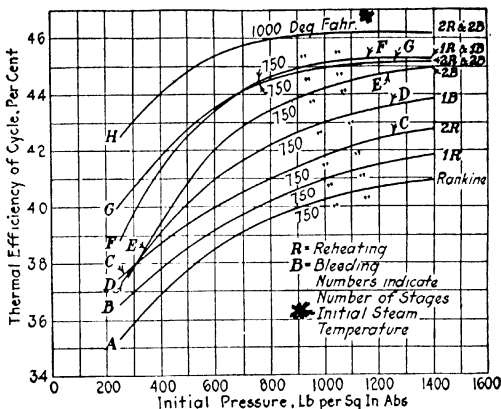
1. EFFICIENCIES OF VARIOUS REHEATING AND OTHER CYCLES

1 in. Hg back pressure. Bleeding points: 1-stage, 240° F., 25 lb abs   2-stage, 280° F., 50 lb., and 180° F., 7.5 in.   Reheating: 1-stage, 140 BTU.   2-stage, 120 BTU each.

W. J. Wohlenberg gives, in Fig. 1, calculated cycle efficiencies for 1- and 2-stage reheating and bleeding, and combinations thereof, for the conditions indicated, which are given as the most favorable. Ideal bleeding cycles are more efficient than the best ideal reheating cycles. The bleeding process improves the efficiency by transferring energy within the cycle, and the reheating process properly used adds energy where its availability for work is high, and also improves the internal machine efficiency of the prime mover. The order of the processes is determined by following the pressure range through. Fig. 2 is a temperature-entropy diagram for a cycle of two bleeding stages with two reheatings between them.

For a given back pressure the adiabatic end point of the expansion process, found by tracing out the ideal cycle on the Mollier chart, is a sort of integrated value of the steam conditions throughout, particularly if the
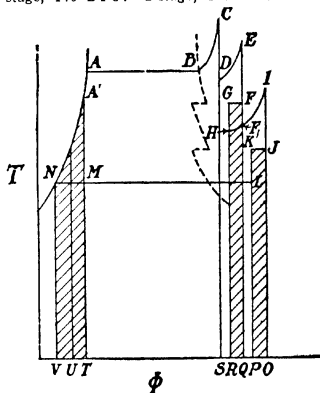
2. CYCLE OF TWO BLEEDINGS AND TWO REHEATINGS

Energy available for work $= A'ABCDEF-$ $GHIJKLNA$.
Net heat added $= A'ABCDEFF'IOTA' +$ $HF'QRH$.
Shaded areas represent heat transferred by bleeding.
Reheat $= SDEQ + RHIO$.
                        —Wohlenberg (A.S.M.E.)

reheating has occurred, as it should, early in the cycle. If for a turbine under consideration test data are available, actual internal machine efficiencies may be plotted against end points, and a table as below constructed:

Initial Pressure lb. abs.	Bleeding Cycles 750° F.		1 Stage Reheating. 750° F		2-Stage Reheating 750° F.		2-Stage Reheating 1000° F.	
	End Pt.	Mach. Effy.	End Pt.	Mach. Effy.	End Pt.	Mach. Effy.	End Pt	Mach. Effy.
300	912	80 8	983	83 4	1035	84 5	1145	85.8
600	865	77.8	940	82.0	989	83.5	1110	85.3
1200	818	71.8	890	79 6	943	82 2	1102	85.2

(End point heat contents in BTU per lb, efficiencies in %)

This shows that unless reheating is used the machine efficiency is relatively low at high pressures, and that for 2-stage reheating at 1200 lb. abs. it is 3% better with 1000° F. than with 750° F. steam temperature. The thermal efficiency at the shaft, based on heat absorbed by the working medium, equals cycle efficiency $\times$ internal machine efficiency $\times$ 99% mechanical efficiency. Curves of shaft efficiency differ from Fig. 1 by curving down to both right and left, the peak efficiency for 750° F. steam being in general below 1000 lb. initial pressure. Reheating is seen to be more efficient than bleeding, due to its good effect on machine efficiency, and the highest efficiency is with the two-stage combination cycle, 2R and 2B. The fact that steam-generating surface naturally falls off in efficiency with increasing pressures will tend to throw the high-efficiency points still farther down the pressure scale.

Reheating surface will normally be included within the boiler setting to withdraw heat from the products of combustion. Mean steam temperatures within them will be somewhat higher than boiler-surface temperatures for 300-lb. and 600-lb. pressures, but for 1200-lb. stations they will actually be somewhat lower. The pressures existing within the reheaters will be considerably below those existing in the boilers, as shown below:

REHEATER PRESSURES FOR VARIOUS BOILER PRESSURES

(Pressures in lb. per sq in abs)

Initial Pressure	Reheater Pressures		
		Two Stages	
	One Stage	1st Stage	2nd Stage
300	88	105	46
600	170	210	70
1200	290	380	120

It appears therefore, that for a given heat absorption, reheater surface advantageously placed may be no more expensive than boiler surface. This would be particularly true if the reheating surface should be exposed directly to furnace radiation, as under these conditions the rate of heat absorption would be very high. Such an arrangement also has obvious advantages when considering maintenance of furnace walls and should lead to higher steam-generator efficiencies because a larger proportion of the total liberated heat energy may be absorbed in the furnace, leaving less energy to be absorbed by convection. The reheater maintenance may, however, be high and there are some operating disadvantages which may make the arrangement undesirable, particularly at light loads when the reheating would be excessive. For high pressures boiler-surface temperatures will be increased with a corresponding rise in the escaping-gas temperature. Economizer surface will, due to high feedwater tempera-

tures, absorb less heat in two-stage than in one-stage bleeding stations. The expected efficiencies for a stoker-fired plant with a steam generator proportioned as shown and absorbing heat at the average rate of 5000 BTU per sq. ft. per hr. are stated below:

A. STOKER-FIRED STEAM GENERATOR EFFICIENCIES

	Steam pressure, lb per sq in	300	600	1200
1-stage Bleeding,	Escaping gas, ° F...	430	500	580
" "	Combined efficiency, %..	82 8	80.8	78.4
2-stage Bleeding,	Escaping gas, ° F...	470	540	620
" "	Combined efficiency, %	81 8	79.8	77.8
Rankine Efficiency, % (90° F. feed water)	. . .. ..	85 2	83 2	80.8

Initial Steam Pressure, Lb per Sq In. Abs.
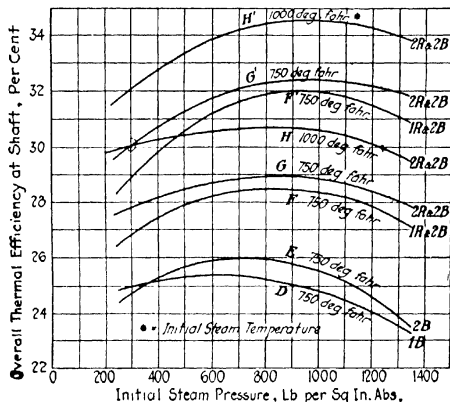
3. OVERALL THERMAL EFFICIENCIES OF A GIVEN STEAM-GENERATING PLANT FOR VARIOUS COMBINATION AND BLEEDING CYCLES

(Auxiliaries, electric generator and pipe-line radiation losses not included.)

Curves D, E, F, G, and H for a stoker-fired plant, 80 to 85% steam-generator efficiency, see table A

Curves F', G', and H' for a powdered-coal maximum-efficiency plant in which steam-generator efficiency is 88% —*Wohlenberg (A S.M.E.)*

Fig. 3 gives the overall efficiencies obtained by combining the thermal shaft efficiencies either with the above steam-making efficiencies, or with 88% for powdered-coal plants. With the stoker-fired plants, no gain may be expected by increasing pressures beyond 850 lb abs. With powdered-coal, air preheaters, increased ratio of economizer to boiler surface, and decreased average rate of heat absorption, 86 to 90% steam-making efficiency may be realized, even for the high-pressure 2-stage-bleeding stations, but to accomplish efficiencies higher than this even in the low-pressure stations would probably involve prohibitive conditions. With 88% steam-making efficiency and 750° F. steam, the maximum overall efficiency point on curve G' occurs at 1000 lb. abs. and equals 32.3%, corresponding to 3415 BTU per Kw. hr./0.323 = 10,300 BTU per Kw. hr.

delivered at turbine shaft. If 10% is charged to generator losses, auxiliary power and pipe-line radiation, the net overall efficiency is 29.1%, and net economy 11,500 *BTU* per Kw hr. at the switchboard. With the suggested combination cycle, pressures materially above 800 lb. abs. for the stoker-fired plant and 900 lb. for the powdered-coal plant result in an actual reduction of economy.

Wohlenberg states that for variable-load operation the reheating coils should preferably be placed in the gas-convection path screened from direct furnace radiation and the load on the steam generators maintained proportional to that of the prime movers. He gives the probable characteristics of a station of net overall economy of 12,000 *BTU* as follows:

Initial steam pressure, 900 to 950 lb per sq in abs
Initial steam temperature, 750° F
Back pressure, 1 in *Hg*
Steam Cycle. Combination $2R + 2B$
  Reheating, 120 *BTU* per stage per lb
  Bleeding, 49 lb and 7.5 in *Hg*
  Condensate 280° F and 180° F.
Steam Generator
  Surface equally distributed between boiler and economizer
  Average rate of heat absorption, 3000 *BTU* per sq ft per hr
  Air-preheater surface per sq ft of surface in boiler and economizer, 0.2 sq. ft.

$$\text{Boiler, superheater, and economizer surface per Kw} = \frac{12,000}{3000} \times 0.88 = 3.52 \text{ sq. ft.}$$

$$\text{Boiler, superheater, and economizer surface corrected for reheating, per Kw.} = \frac{1345 - 248}{1345 - 248 + 240} \times 3.52 = 2.89 \text{ sq ft.}$$

Reheating surface per Kw. depends on position
Energy absorbed in reheater per Kw-hr = 1900 *BTU* = 18% of total.
Air-preheater surface per Kw = 0.2 × 3.52 = 0.70 sq ft
Temperature of gases escaping from boiler, 620° F
Temperature of gases escaping from economizer, 350° F
Temperature of gases escaping from an preheater, 260° F
Draft loss in boiler and economizer, 1 in water
Draft loss in air preheater, 4 to 5 in water
Fuel: Powdered coal burned with 20% excess air

W. E. Blowney and *G. B. Warren* have investigated the gains from **resuperheating**, due largely to increase in turbine efficiency from greater superheat and reduced moisture content of the steam in the turbine, rather than to thermodynamic improvement of the heat cycle. Considering known turbine characteristics and the automatic "reheating" of steam due to energy losses in the individual stages, and assuming dry-stage efficiency to vary from stage to stage, they give the data in Fig 1, showing the gain in net thermal efficiency due to a single resuperheating at points indicated, expressed as % of the thermal efficiency without resuperheating. The curves are relative, not absolute, ignoring last-stage leaving losses, bearing, packing and generator losses, and also the pressure drop in the resuperheater and its piping, which would probably reduce the gain by ½ to ¾%. The gain is greater at the higher initial pressures, whereas the theoretical gain, considering the heat cycle alone, is lower at the higher pressures. This is due to the fact that a greater portion of the turbine is operating in the moisture region with the high initial pressures and so is susceptible of greater improvement. The best point for resuperheating comes at ⅕ to ⅙ of the initial pressure, and for initial pressures of over 500 lb. abs. this calls for resuperheating piping of only moderate size. It is assumed that dry-stage efficiency is highest in the low-pressure end, and
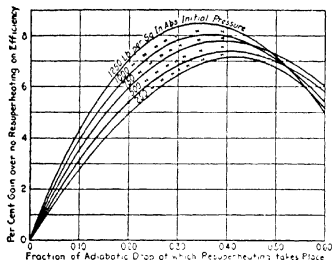
1. GAIN IN TURBINE THERMAL EFFICIENCY DUE TO RESUPERHEATING

Initial and resuperheating temperature, 750° F. Back pressure 1 in Hg abs. Variable stage efficiency as function of stage pressure. No pressure drop in resuperheater.
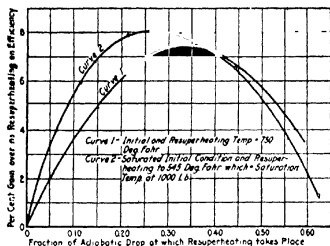
2 EFFECT OF INITIAL TEMPERATURE ON THERMAL EFFICIENCY GAIN

Initial pressure 1000 lb. abs., 1 in. Hg abs. back pressure, no pressure drop in resuperheater.
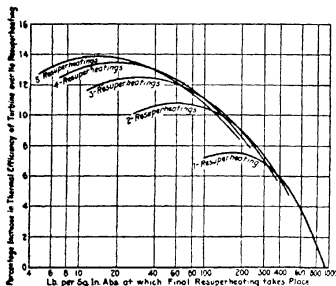
3. THERMAL EFFICIENCY GAIN FROM MULTIPLE RESUPERHEATING

½% reduction in economy assumed for each resuperheating, due to pressure drop. Initial pressure 1000 lb. abs., 1 in. Hg abs. final back pressure, resuperheating to 750° F.
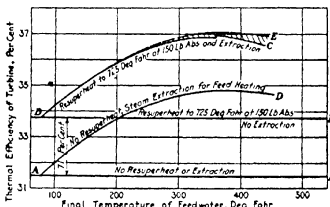
4. COMPARATIVE THERMAL EFFICIENCY WITH EXTRACTION AND RESUPERHEAT

Initial pressure 515 lb. abs. Resuperheating at 150 lb. abs. Initial and resuperheating temperatures 750° F. Back pressure 1 in Hg abs. 3-stage extraction.
—*Blowney & Warren (A.S.M.E.)*

this assumption shows gains from superheating ½ to 1% greater than with the less probable assumption of constant stage efficiency. Taking the initial pressure as 1000 lb. abs. and the reheating pressure as 150 lb. abs., it was found that the gain remained practically constant at 7.5% when the total initial and resuperheat temperatures varied from 550 to 750° F., but remained mutually equal, although the theoretical gain rose from 0.7% to 2.5% under the same circumstances. Figure 2 shows comparative curves giving the % gain in thermal efficiency when reheating or resuperheating at various fractions of the adiabatic drop with initial and resuperheat

temperatures of 750° F. in one case, and in the other case equal to saturated steam temperature at 1000 lb. abs. These curves indicate that the best point for resuperheating is not necessarily the point at which the steam in the high-pressure turbine loses its superheat, as is quite commonly believed.

Fig. 3 gives the net gain from multiple resuperheatings, assuming the loss from pressure drop per operation to be ½%, which is somewhat lower than present practice. The gain in going from two to three stages of resuperheating becomes so slight as to offer slight inducement to accept the increased complication and expense, while two resuperheatings might be warranted in large high-pressure base-load units. The gain in thermal efficiency with a combination of resuperheating and regenerative cycles is stated to be practically 95% of the sum of the gains when used separately, on account of the small proportion of the heat in the extracted steam which is due to the superheat. Figure 4 shows a resuperheating and a non-resuperheating cycle with steam extracted at three equally spaced points for heating the feed water in both cases. The curves were made so as to show the gain in each case when heating the feed water to different temperatures. The feed heating calculations were made on an ideal basis, assuming no temperature drop, no pressure drop and contra-flow conditions in the heaters, so that the drip from each heater left the heater at the temperature of the incoming feed water. The drip was drained into the next lower heater in each case.
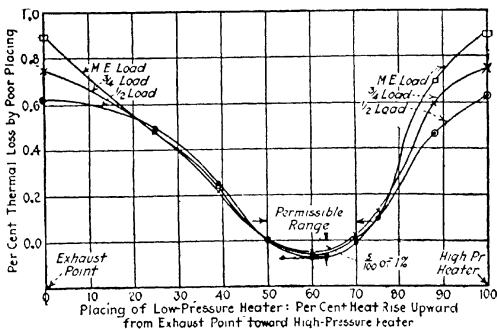
A. EFFECT OF POSITION OF LOW PRESSURE HEATER

Fig. *A*, by *E. H. Brown* and *M. K. Drewry*, shows the effect of the location of the first heater in a 2-stage extraction heating cycle, the second heater heating to 210° F., and the turbine operating at ½, ¾ and most economical load. Best economy is obtained when operating with the low-pressure heater at a point 60% of the heat-drop interval upward from the exhaust, or in this case at a pressure of about 4 lb. abs. Under these conditions slightly more heat is transferred in the low-pressure heater, though considerably more power is lost in steam extracted from the high-pressure nozzle. Accurate placing of heaters is not of importance, for, as the curve shows, any position from 50 to 70% of the heat drop causes a change in
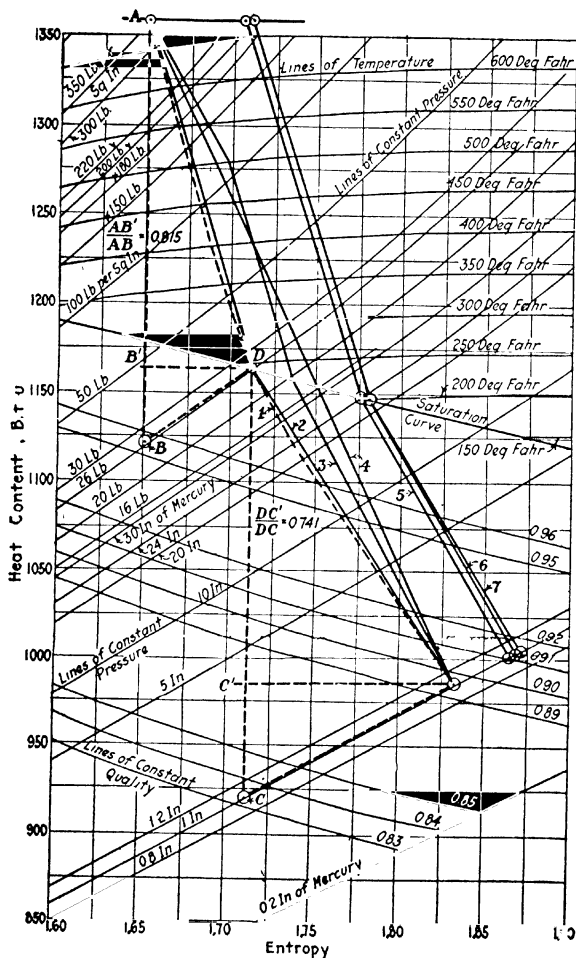
B. VARIOUS TYPES OF EXPANSION LINES—*Brown & Drewry*

No. 1—Test characteristics of the straight reaction-type turbine. No. 2—Easily drawn straight line expansion approximating line 1, by showing 10% greater efficiency in superheat field than in saturated field, gives data of high accuracy for feed water-heating calculations. No. 3—Estimated expansion line of a combination velocity-compounded impulse and reaction turbine. No. 4—Approximate expansion in a straight impulse machine, velocity-compounded in high-pressure blading and pressure-compounded in exhaust. No. 5—Half-load expansion when extracting 15% steam from a straight reaction turbine not previously proportioned by the manufacturer for extraction. Inlet pressure has been increased 10 lb. above the normal non-extraction value. No. 6—Half-load expansion when extracting steam from a unit proportioned by the manufacturer for the given percentage of extraction. Inlet pressure is identical with the value upon which the guarantees are based. No. 7—Expansion line when not extracting. Separation from line 6 near exhaust is due to decrease in leaving losses resulting from extraction.

economy no greater than $\frac{1}{20}$ of 1%. In three- or four-heater cycles slight preference should be given low-pressure heaters in distributing the heat loads, working the high-pressure ones at lighter values, though this adjustment is not strictly necessary. In computing two three-heater cycles having the ratio of heat absorbed in each heater, starting with the high-pressure heater in each case, 1.0-1.6-1.1 and 1.0-0.97-1.8, respectively, a difference in heat consumption of the order of 0.01% was found. A representative two-heater cycle, heating to 210° F. at most economical load and containing a steam-jet air pump, showed increases of 1.1%, 0.84%, and 0.71% in heat consumption at $\frac{1}{2}$, $\frac{3}{4}$, and most economical loads, respectively, above the same cycle computed without an air pump. True, average steam consumption of the air pump (0.8% of full-load throttle total steam) heated the feedwater as much as 15° F., but this being done at an extremely low temperature level by high-temperature-level steam resulted in decreasing the benefits of extraction heating from, for example, 5.5 to 4.5%. The fallacy of crediting the steam-jet air pump, injector, and other steam auxiliary equipment in power stations with 100% efficiency is thus indicated. Were two-stage steam-jet air pump equipment so constructed that an extraction heater could be interposed between the two effects, these losses could be lessened to 0.96%, 0.725%, and 0.64%, since most of the air-pump aftercooler heating could be done at a higher temperature level. If mechanically practical and fully as reliable as the steam-jet air pump, economical motor-driven vacuum pumps, with air pumps in reserve as "augmenters" or as auxiliaries when starting, would be desirable equipment, though continuity of service is of great importance in this consideration.

Since extraction gains are caused by obtaining work from the extracted steam before it passes to the boiler, the amount of work done in the machine down to a given pressure is a criterion of extraction efficiency. Machines with inherently inefficient high-pressure stages are at a disadvantage therefore in producing economy in extraction feed-heating systems. A 2-heater cycle heating to 210° F., calculated from expansion lines 3 and 4, Fig. B, velocity-compounded turbines, at the most economical load, gave results 0.24 and 0.325 % poorer than curve 2, calculated for a straight reaction-type turbine. The latter has high-efficiency high-pressure blading and moderate-efficiency low-pressure blading; the former, to indicate comparable overall efficiencies, must have very high-efficiency low-pressure blading to counteract inevitable losses of the high-pressure blading. The extracted steam experiences these losses, but leaves the machine too early to compensate for them in the exhaust blading, with the net results indicated. Due to the low temperature level of the generator air and bearing oil, their utilization is questionable for purely thermal considerations, so long as feedwater is heated by stage extraction.

In Fig. C the authors give the saving in heat consumption with one-to four-stage heating to different maximum temperatures, compared with non-extraction operation. In agreement with other investigations, the curves show maximum benefits to occur at 245, 300, 320 and 330° F. respectively, for 1, 2, 3 and 4-heater cycles, for "most economical" turbine load. The fractional-load curves for the 1- and 2-heater cycles show the maximum economy obtainable, not with constant feedwater temperature, but with changes just as they occur at extraction nozzles with variable loads, represented by the straight lines joining the calculated points in both systems. The straight lines AB and $A'B'$ not only cut the peaks of each set of curves, but indicate the natural drop in temperature at the specific
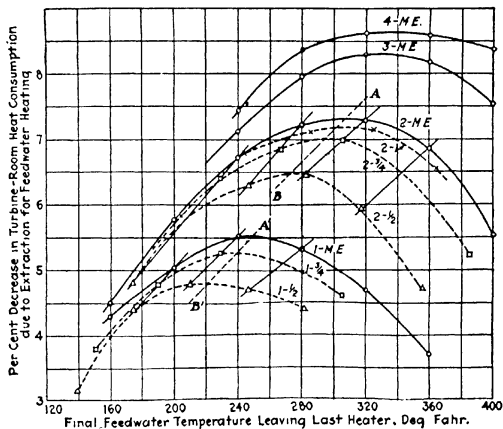
C. HEAT SAVING BY EXTRACTION HEATING

From computation of complete cycles, considering all extraction variables, except leaving loss, for 20,000-Kw straight reaction high-pressure turbine, but applicable to others with small error The numerals 1, 2, 3, 4, indicate number of heaters used. ½ and ¾ refer to fractions of full turbine load. *M E.* = most economical load.
—Brown & Drewry (A.S M.E.)

nozzle heating feedwater to those most efficient temperatures. Unless boiler-room practice rigidly requires constant feedwater temperatures at economizer inlets, the inherent simplicity of extraction stage heating can thus be maintained. Increase in the number of heaters, besides improving economy at any given final temperature and increasing the most economical temperature, broadens the range over which the system can operate without causing great decrease in economy. Three- and four-heater curves are appreciably flatter than those for one and two. The proportionate gain in installing additional heaters decreases rapidly, especially at present
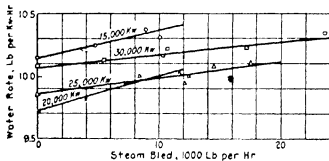
1. EFFECT OF BLEEDING ON
    TURBINE WATER RATE
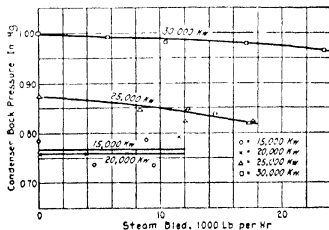
2. EFFECT OF BLEEDING ON CON-
    DENSER BACK PRESSURE
    —Zimmerman (A.S.M.E.)

temperatures, although an increase in final feedwater temperatures would favor the use of larger numbers of heaters.

C. D. Zimmerman gives test data as to the effects on **actual turbine** performance of single-stage bleeding from the 13th stage of a 17-stage 30,000-Kw. Curtis-type turbine. Fig. 1 shows the change in *water rate* with respect to steam bled, for different turbine loads, throttle pressure 235 lb. gage, 250° F. superheat An increased rate naturally occurs when part of the steam by-passes the last stages, although this effect is partly compensated for by the decrease in condenser back pressure Fig. 2 shows the decrease in condenser *back pressure* with increase in steam bled, due to reduction in weight of steam sent to condenser and to its increased moisture content. Fig. 3 shows the increase in feed water temperature with increased bleeding, based on actual operating cycle, and including exhaust from the steam auxiliaries.

The boilers were Duplex Stirling, 30,600 sq ft., with convection super-heaters, 4520 sq ft., 835 sq ft water-tube screens and 22,080 sq. ft. economizer surface. The decrease in *boiler-unit efficiency*, Fig. 4, with increased bleeding, results from an increase in the feed temperature which causes an increase in the economizer exit gas temperature. Under normal operating conditions, this heat loss in the economizer will be slightly compensated, due to the fact that the rate of driving at which it is necessary to operate the boiler for a given generator output will decrease with increase in feed temperature. At 25,000 Kw. load, the rate of driving is reduced from 180% of rating with no bleeding, to 175% when bleeding 20,000 lb. steam per
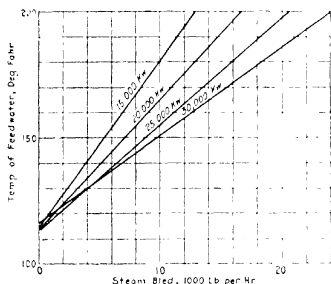
3. EFFECT OF BLEEDING ON FEED
   WATER TEMPERATURE
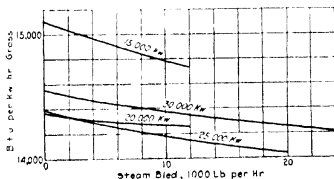
5. EFFECT OF BLEEDING ON
   GROSS *BTU* PER KW.-HR.
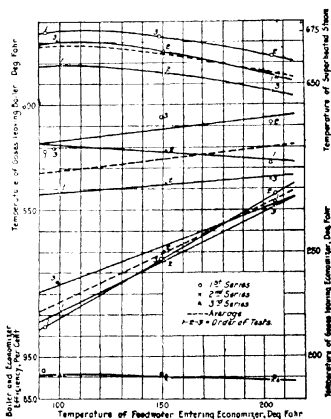
4. EFFECT OF FEED TEMPERATURE
   ON BOILER UNIT

Test data corrected to 12 9% CO_2 and
180% boiler rating.

—*Zimmerman.*

hr. The initial superheat decreases with amount of steam bled, due to decrease in rate of driving boiler and increased steam flow through the superheater.

The table below gives the total plant performance at 25,000 Kw. load. This was prepared by using the water rates in Fig. 1 and the average auxiliary water rates, calculating the feed temperatures and the superheat from Fig. 4, then recalculating the water rates, considering these temperatures, the driving rate and the resulting efficiencies. The last line, giving gross *BTU* per Kw.-hr., is representative of actual steady-load conditions, but does not include losses which would be incurred under varying load. Fig. 5 shows the change in gross *BTU* per Kw.-hr. for different constant generator outputs; the peculiar shape of the 20,000-Kw. curve is possibly due to an insufficient number of tests at this load.

EFFECT OF STEAM BLEEDING AT 25,000 KW.

Steam bled, lb. per hr.	0	7,000	14,000	20,000
Steam bled, %	0	2.69	5.30	7.48
Turbine water rate, lb. per Kw.-hr.	9.71	9.83	9 98	10.11
Auxiliary steam water rate, lb per Kw -hr.	0.24	0 24	0 24	0.24
Misc. steam water rate, lb per Kw.-hr.	0 34	0 34	0.34	0.34
Total water rate, lb. per Kw -hr.	10.29	10.41	10.56	10.69
Feed Water, ° F.	113 2	143 4	172 7	197.1
Superheated steam temp , ° F.	668 7	663.4	657.0	651.3
Boiler rating, %	180.0	177.7	176 0	175.3
Boiler and econ. efficiency, %	90 5	90 2	89 8	89.5
Gross *BTU* per Kw.-hr.	14,392	14,225	14,115	14,021

For installations without economizers, the change in boiler performance with a change in feed water temperature will probably be greater than for installations with economizers, as the economizer has the effect of absorbing part of the change in feed temperature, and the temperature rise through the economizer decreases with increase in feedwater temperature. The effect of a change in superheat due to steam bleeding pertains more to existing installations than to the design of new plants, as in the latter case the superheater can be designed for the feedwater temperature decided upon. Fig. 6 gives the financial saving at 25,000 Kw. load and 70% load factor, due to bleeding steam from the 13th stage, deducting 15% of the total cost of installing the bleeder heater to give the net saving. For similar equipment which would not involve additional investment charges for higher feedwater temperatures it is believed that the economical feed temperature would be below 250° F.

The tests also supplied the data for Fig. 7, giving the change in turbine water rate with variable back pressure. At the low back pressure of 0.4 in. mercury there is still a decrease in water rate with a decrease in back pressure, for loads up to 25,000 Kw., but the limiting condition for a load of 30,000 Kw. is about 0.7 in. Fig. 8 gives the change in turbine water rate due to change in superheat. The change in water rate per 10° in superheat ranges from 0.7% at 15,000-Kw. load to 1% at 25,000 Kw. Fig. 9 shows the effect of air in the steam going to condenser on the vacuum obtainable, when carrying 25,000-Kw. load, additional air being purposely admitted to the turbine exhaust casing through measuring nozzles. The upper curve gives the vacuum maintained as a fraction of the total air removed from the condenser, the lower one as a function of the rate of air admission to the exhaust casing.
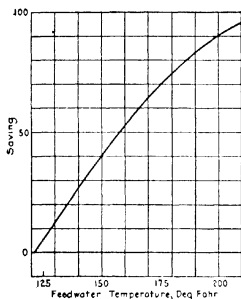
6. FINANCIAL SAVING (in Abstract Units)
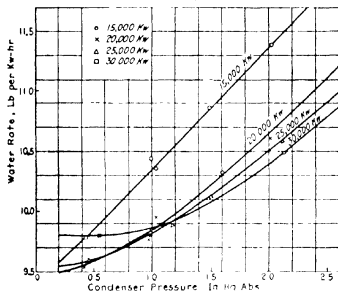
7. EFFECT OF CONDENSER BACK PRESSURE ON TURBINE WATER RATE. (Steam 250 Lbs. Abs., 250° F. Superheat.) —*Zimmerman.*
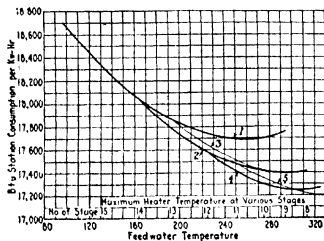
EFFECT UPON STATION ECONOMY OF EXTRACTING STEAM FROM MAIN UNIT TO HEAT FEED WATER.—*G. G. Bell.*
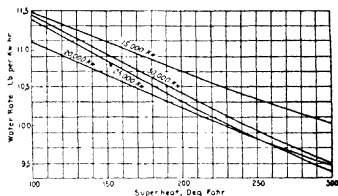
8 EFFECT OF SUPERHEAT ON TURBINE WATER RATE (Initial Steam 250 Lb. Abs, Condenser 1 in. Hg Abs)
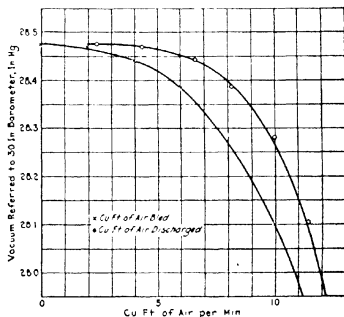
9 EFFECT OF AIR ON CONDENSER VACUUM—*Zimmerman*

Based upon 30,000 Kw. turbine carrying 28,000 Kw. load with 78% efficiency, receiving steam at 300-lb gage and 200° F superheat from a 20 tube-high cross-drum boiler and exhausting to 1-in. mercury back pressure Curve 1 is for single-stage extraction 2 and 3 for two stage heating, using the 13th and 14th stages, respectively, as the first bleed point and 5 for triple-stage heating, using the 14th, 11th and 8th stages By adding 60% economizer surface the best feed water temperatures could be reduced by 40° to 50° F. in each case.
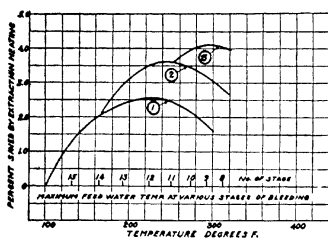
A. With Low Boiler and Economizer   B. With High Boiler Only
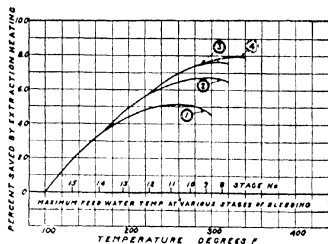
GAINS FROM USING MULTISTAGE HEATING
Ringed figures indicate number of bleed points.
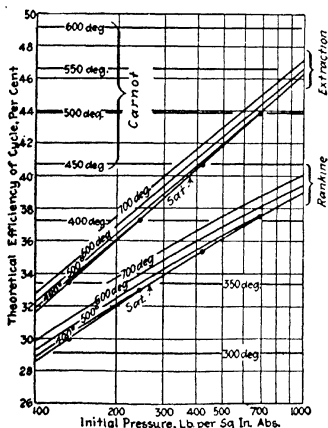
THEORETICAL EFFICIENCIES OF
STEAM CYCLES—*E. L. Robinson.*

Efficiencies of perfect steam cycles using steam at various initial temperatures and pressures and with 1 in. mercury back pressure. Curves are for various initial total temperatures, ° F., as indicated. Back pressure, 1 in. Hg.

Figs. A and B, from the *Prime Movers Committee* Report of May, 1924, show the savings from the use of various numbers of stages of extracting heat with an economizer and with a "high" boiler respectively, figured with a 28,000 Kw. turbine for 29-in. vacuum and with the condensate heated to 100° F. by gland steam and air and oil coolers.
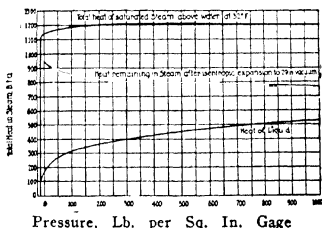
TOTAL HEAT OF SATURATED STEAM, ALSO HEAT OF THE LIQUID AND HEAT REMAINING AFTER ISEN-TROPIC EXPANSION—*W. Slader*, in *Power.*
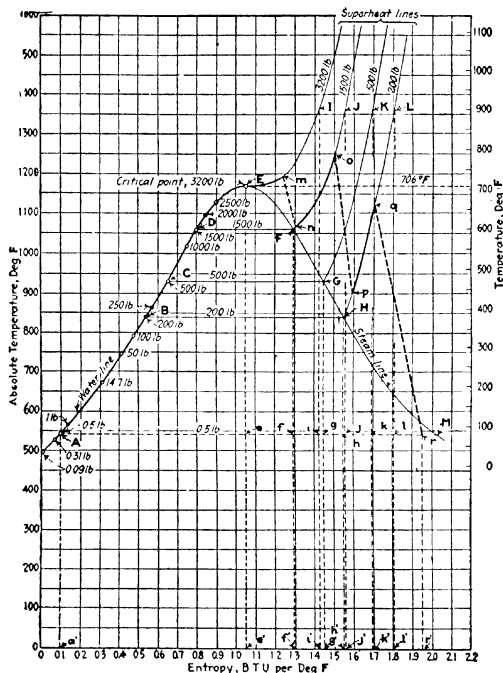
TEMPERATURE-ENTROPY DIAGRAM FOR HIGH-PRESSURE STEAM

Line *m n o p q r* shows reheating cycle, in which steam is withdrawn from the turbine
and superheated during expansion

William F. Ryan discusses the value of higher steam pressures in the
industrial plant, stating that the increase in thermal efficiency obtained by
using pressures over 400 lb. in the condensing plant can hardly exceed 20%,
while in the industrial plant the gain may be 75% or more, if the use of
higher initial pressure permits the substitution of non-condensing prime
movers, whose exhaust steam is used in process, for condensing units.

In plants not requiring process steam, the ability to generate power at
any reasonable cost is limited by the amount of steam that can be con-
densed with the available water. In many plants the power demand is
increasing while the steam demand per unit of production is being reduced,
calling for increased power per unit weight of steam. Cycle efficiency need
not be considered, as it is always 100%, provided that the heat in the
exhaust is fully utilized, while the actual efficiency is as close to 100% as
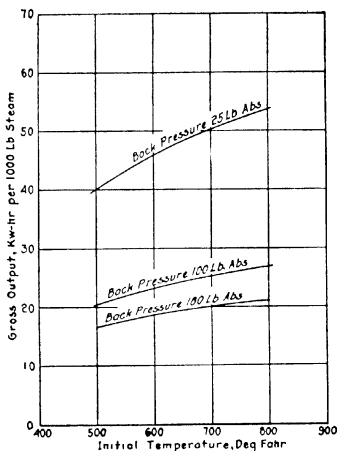
1. EFFECT OF INITIAL TEMPERA-
TURE ON POWER OBTAINABLE
FROM STEAM AT 565 LB. ABS.
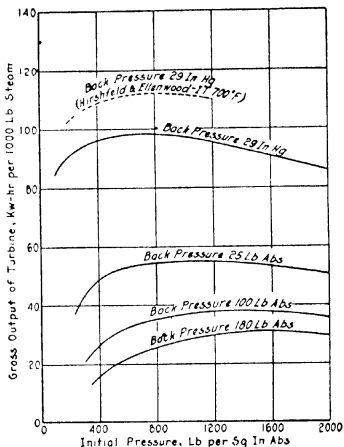
2. EFFECT OF INITIAL PRESSURE
ON POWER OBTAINABLE FROM
STEAM AT 725° F.
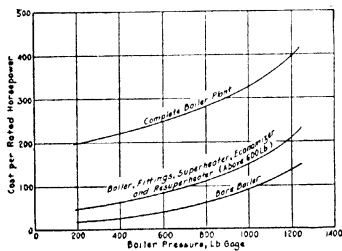
3. INCREASE IN BOILER-PLANT
COSTS WITH INCREASE IN
PRESSURE
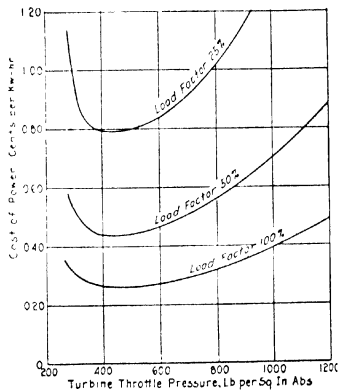
4. EFFECT OF INITIAL PRESSURE
ON COST OF POWER. THROTTLE
TEMP. 725° F.. EXHAUST STEAM
AT 180 LB. ABS., 535° F.
                    —Ryan (A.S.M.E.)

mechanical, electrical and radiation losses will permit, regardless of initial or final pressure and temperature. The water rate of the prime mover is important, not because a low water rate saves fuel, but because it permits the generation of more power from a given weight of steam. A radiation loss which amounts to 10% of the total heat consumption in a condensing unit would amount to more than 30% in a high-back-pressure machine.

Fig. 1 shows how the gross output of a non-condensing turbine, per *unit weight* of steam used, is increased by increasing *throttle temperatures.* The gain is relatively less at the higher back pressures but is considerable under any condition. A turbine operating between 565 and 180 lb. per sq. in. abs. will deliver about 6% more power per unit weight of steam with an initial temperature of 725° F. than with 650° F. A more important point than the increase in output per unit weight of steam is that high initial temperature produces a higher quality of exhaust steam, making it possible to use high initial pressures without resuperheating the steam during expansion. In the following comparison of pressures, a throttle temperature of 725° F. has been assumed, with the idea that a plant can be designed for safe and dependable operation at that temperature, while the use of a materially lower temperature will not yield the best obtainable results from high pressures.

Fig. 2 shows the effect of *throttle pressure* on output per *unit weight* of steam (*not per BTU*) for *non-condensing* turbines, without resuperheating of the steam during expansion, resulting in exhaust of varying quality, depending upon the initial pressure It will be noted that the optimum throttle pressure increases as the back pressure increases With a final pressure of 25 lb. abs there is no gain by increasing the throttle pressure above 750 lb., while at 180 lb abs. back pressure, the maximum output is obtained with an initial pressure of about 1550 lb The dotted curve shows *Hirshfeld & Ellenwood's* figures for 30,000 Kw *condensing* turbines under test conditions, the one below it representing condensing units of 1500 to 5000 Kw. capacity, operating under the average part-load conditions of the industrial power plant The curves in Fig. 2 are on the assumption that the expansion line of a steam turbine above or below the saturation point may be plotted as a straight line on the Mollier diagram, and that the stage efficiency of a turbine may be considered to be 10% less in the wet zone than it is above saturation temperature.

Fig. 3 shows the relative estimated costs of a plant, for one particular set of conditions, for various pressures Actual cost would not, of course, be a smooth-curve function of the pressure, but would make definite increases at definite pressures. The plant is designed to include sufficient economizer and air-preheating surface to give the same final flue-gas temperature (300° F.) and as nearly as possible the same operating efficiency at all pressures. No charge is included for real estate. The cost of building is about 30 cents per cubic foot. Stoker firing is assumed and stokers and auxiliaries are designed for a maximum output of 350% of boiler rating. It will be noted that while the cost of a 1200-lb. boiler is about four times that of a 400-lb. unit, the cost of the complete plant at the higher pressure is less than twice as great. The cost of a turbo-generator increases relatively less, with increased pressure. While the prices vary widely with different designs, a machine for 1200 lb. initial pressure and 180 lb. back pressure will not cost more than 50% more, installed, than a machine of the same size and back pressure for 400 lb. initial pressure.

Cost of power has been estimated as follows: To the cost of boiler plant as estimated in Fig. 3 has been added the cost of turbo-generators of sufficient capacity to use the steam generated by the boilers when operating at 200% of rating. The average boiler output is assumed to be 160%, but higher ratings are necessary when one or more boilers are out for inspection or repairs. From this total cost has been subtracted the cost of a 200-lb. boiler plant designed to produce the same quantity of steam at the same pressure and superheat as that exhausted by the turbines. This difference is taken as the cost of the power-producing equipment. Straight-line depreciation in fifteen years, taxes and insurance at 3%, and the excess cost of maintenance, labor, and supplies over that required in a 200-lb. boiler plant without generating equipment are added to the cost of fuel required to supply the heat consumed in the turbines. A boiler-plant efficiency of 85% is assumed at 100% load factor, 80% at 50% load factor and 72% at 25% load factor. Cost of coal is taken at $5 per net ton, delivered at the stokers. The resulting costs per unit of output are shown in Fig. 4, which is only a graphic representation of the estimated costs of power and does not indicate the best steam pressure to be used. If a similar chart were prepared for a central station, the costs should include return on invested capital, and the optimum pressure would be that at which cost is a minimum. The problem in the industrial plant is to get the required power from the available steam, a chart like this will show how much of it may be obtained more cheaply from high-pressure turbines than from other available sources.

At one plant where a high-pressure installation is being contemplated, power cannot be generated condensing for less than one cent per kilowatt-hour, and power, dependable or otherwise, cannot be purchased for less than 0.75 cents per kilowatt-hour. The load factor is exceptionally high, averaging over 80% for the year, and over 90% for any month. If dependable equipment could be obtained, it would pay, in this case, to use pressures up to 1200 lb. per sq. in., if that were necessary, to generate the required amount of power. The return on the difference in invested capital for a 1200-lb. non-condensing plant over a 200-lb. condensing plant, would be at least 50%.

With a back pressure of 180 lb. per sq. in. abs., as much power can be generated by 1000 lb. of steam in an engine-generator operating with an initial pressure of 400 lb. abs. and initial temperature of 650° F. as in a turbine operating at 500 lb. abs. and 725° F. The superheat in the exhaust is, of course, less, and if the same final conditions are to be obtained, the exhaust must be resuperheated. The radiation losses in the engine are much greater than in the turbine, and consequently the net heat consumption per unit of output is greater. The total installation cost of an engine-generator to operate between 400 and 180 lb. abs. is about twice as much as for a turbine of the same capacity operating under the same conditions. For equal power developed from a given quantity of steam, the cost of the engine installation would be somewhat less than that of a turbine, due to the fact that a lower pressure could be used. Which type prime mover will furnish the cheaper power is largely a function of load factor, the higher first cost of the turbine plant being the more important factor at low load factor, and the higher heat consumption of the engine being the more important factor at high load factor. While a greater amount of power can be generated in the engine, from a given quantity of steam, the

net effect at the coal pile is the same as if part of the power were generated in high-back-pressure turbines and the remainder in condensing units.

The capacity of many kinds of steam heating equipment is increased with increased pressure, or conversely, the size and cost of equipment for a given output is decreased with increased steam pressure. Higher pressures in evaporating processes usually increase the capacity, the heat economy, or both. A typical case is that of a plant using multiple-effect evaporators for the concentration of a liquor. Steam at 150 lb. and 135° F. superheat is used in prime movers, exhausting at 10 lb gage. The exhaust steam, which is approximately 94% dry, is used as a heating medium in triple-effect evaporators. By increasing the back pressure to 25 lb. a fourth effect could be used, reducing the steam consumption approximately 25%. By increasing the initial pressure to 375 lb and the initial temperature to 625° F., the same quantity of power could be generated on this reduced quantity of steam. That is, the total power and heating demand could be taken care of with 25% less steam. The total heat of steam as supplied to the prime mover would be greater, but the heat returned to the boilers in the drip from the first-effect evaporator would also be higher; the actual heat consumed per pound of steam would be slightly less. There should be a net fuel saving in the complete operation of at least 25%. Many plants are using live steam in process work at 40 to 100 lb. pressure. Reducing the pressure from that supplied at the boilers often results in a troublesome degree of superheat, as well as in a waste of available energy. High-back-pressure prime movers remedy this situation

Manufacturers of heating equipment such as evaporators have made little change in limiting pressures in the last twenty years. Pressures up to 100 lb. per sq. in. were used on large evaporators at least twenty years ago, and very few, if any, large evaporators have been built for higher pressures. While temperature increases rather slowly with increased pressure, it is usually possible to increase the efficiency of an evaporating process by increasing the steam pressure. With a highly concentrated liquor which has such a high boiling temperature that only single-effect evaporation can be used with steam at 100 lb. per sq. in. pressure, two effects could be used with a pressure of 250 lb. without reducing the mean temperature difference between the steam and the liquor. The design of an evaporator with a shell 16 or 20 ft. in diameter for very high pressures presents some problems, but few which have not been solved in the Scotch marine boiler.

The effect of pressure on turbine efficiency can be judged from Fig. B, by *Eskil Berg*. With gage pressures around 200 lb. and super-
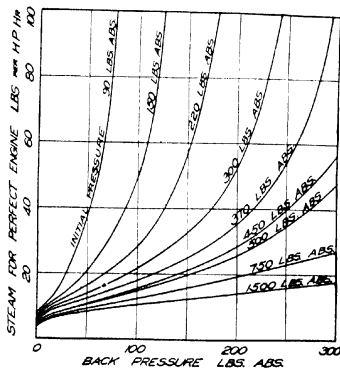
A. ENGINE STEAM CONSUMPTION
AS AFFECTED BY PRESSURES
—*O. H. Hartmann.*
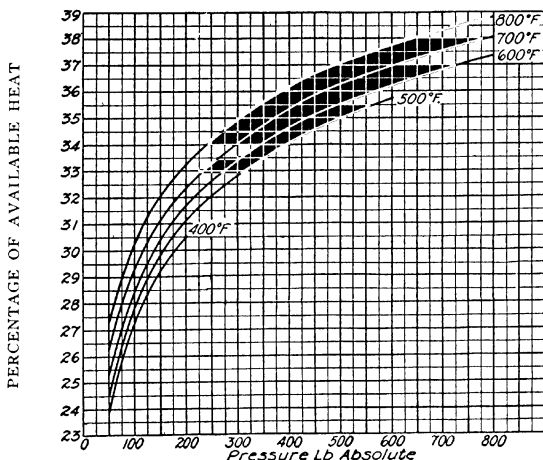
B. RATIO OF AVAILABLE *BTU* TO TOTAL HEAT
ABOVE 90° F IN STEAM AT DIFFERENT PRESSURES
AND TEMPERATURES —*A S M E.*

heats of 150° (538° F. steam temperature), as ordinarily used in turbine power plants, the thermal efficiency is only 31.25%, while with 700° steam and 500 lb. pressure, an efficiency of 36% can be obtained, with a comparative fuel saving of 16%. By the use of 800° steam at 800 lb. pressure with an 85% efficient turbine and an 88% efficient boiler, a Kw-hr. could be obtained on 0.62 lb. of oil, which approaches the best claims for Diesel engines requiring a much more expensive grade of fuel.

Which **heat balancing** arrangement is best depends upon considerations such as size of plant, load factor, character of load, etc   Certain heat balance methods which are economical with a constant load result in waste with fluctuating loads, and obviously a greater degree of refinement and more complicated arrangements are justifiable in large stations where the auxiliaries run into thousands of horsepower than in small plants where the main units themselves may be of but a few thousand or hundred horsepower. In general, however, the following statements will hold:

(a) The heat balance system should promote the overall economy of the plant as much as is practicable.

(b) It should also promote the reliability of the plant, or at least be free from danger. Interlocking of different systems or units, as where auxiliaries are tied to the same bus bars with main units, or mechanically driven from the latter, should be avoided or the arrangement should be made incapable of interfering with plant operation.

(c) The plant should be simple to operate, with few valves, gages or controls requiring attention.

(d) Complicated piping should be avoided, particularly in large plants.

(e) Standard design and construction should be departed from as little as possible, as this increases cost.

(f) The arrangement or layout adopted should fit in with possible future extensions or improvements, such as the subsequent introduction of economizers, etc.

Methods of Driving Auxiliaries—As the heat balance arrangement is closely related to the method of driving auxiliaries, typical examples of such methods will be discussed.

Auxiliaries driven directly from the main unit, with no feed heater—This system, which is employed principally in marine power plants and to some extent in water works pumping stations, gives simplicity in piping, with few steam using units, but does not result in maximum plant efficiency, since regenerative feed heating is absent. The useful output of the main unit is diminished by the amount of power required to drive the auxiliaries and the auxiliaries are dependent upon the operation of the main unit, also speed control of auxiliaries is difficult, if not impossible.

Motor driven auxiliaries using current from main unit, with no feed heater—This arrangement offers flexibility in speed control of auxiliaries, which are, however, dependent upon the main unit. An expense is incurred for transformers, distributing circuits, motors, etc., and power is lost in transformation. The thermal efficiency of the plant suffers by the absence of feed heaters.

Independent steam driven auxiliaries, with feed heater—With this arrangement the auxiliaries are independent of the main unit and the power for auxiliaries is produced at the cost of only the equivalent amount of heat. The boilers are fed with hot water, which can be deaerated and softened, if required. There is, however, considerable complication in piping, besides the cost of steam ends for auxiliaries. The steam used for feed heating does not develop the maximum amount of power. Under variable load conditions the amount of such steam is not easily adjusted to feed heating requirements, resulting either in low feed temperatures at times of heavy load or in waste of steam at times of light load, or both. This arrangement, however, is still generally used in industrial plants, particularly where there is a demand for low pressure steam for heating or processes.

Duplex drive for auxiliaries, with feed heater—With combined motor and steam drive for each of the main auxiliaries, the amount of exhaust

STEAM FOR CENTRIFUGAL PUMPS
—B. C Sprague in *Power Plant Engg*

Comparison of steam required for driving centrifugal boiler feed pump by an auxiliary turbine with the steam required to be added at the main turbine throttle to generate the power taken by a boiler feed pump motor and to permit of bleeding steam for feed water heating equivalent to that done by steam exhausted by the turbine-driven boiler feed pump.
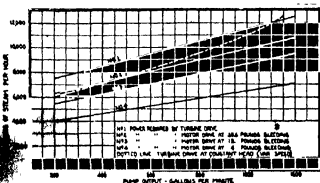
for feed water heating can readily be adjusted to meet requirements and the auxiliaries, if occasion demands, are independent of the main unit. The boilers can be fed with hot, deaerated and softened water. There is flexibility of speed control when using the steam ends for driving the auxiliaries and part of the power for auxiliaries is produced at a low heat cost. On the other hand, the arrangement involves multiplicity of units, complication of piping, cost of transformers, wiring, controllers and motors, in addition to the cost of steam prime movers for the auxiliaries, and the maximum amount of power is not obtained from the steam used for heating feed water. In most plants, however, provision is made for steam drive of one or more boiler feed pumps, and there is a tendency to install duplex drives for exciters.

Motor driven auxiliaries using current from house turbo-generators exhausting to feed heaters.—This arrangement gives an efficient steam cycle, although not always quite so efficient as where the steam for feed heating is bled from the main unit, since the house turbines are not so efficient as the latter. However, in very large plants, the house turbines may be as efficient as the high pressure end of the main unit when the losses in transformers and converters or motor generators are taken into consideration. This applies particularly where direct current is wanted in order to secure more flexible speed control of auxiliaries. Again, if the exhaust of the house turbine or of a steam-driven auxiliary can all be condensed in heating the feed water to a temperature lower than that of the lowest bleed point on the main turbine, it will not injure, but rather improve, the plant efficiency, no matter what its own efficiency may be. In order to meet this condition, however, it can have only limited capacity.

The house turbo-generator plan has the advantage of few steam using units, simplicity of piping, auxiliaries independent of the main unit, output of the main unit undiminished, flexibility in location and speed control of auxiliaries, together with the possibility of deaerating and softening the boiler feed water by using the house turbine exhaust for these purposes. It is necessary to adjust the output of exhaust steam from the house turbine to meet the water heating requirements, for which purpose the following arrangements are available, all, however, presenting the possibility that electrical disturbances in the main circuit may to some extent interfere with the operation of auxiliaries.

(1) A motor generator or rotary converter unit tying the auxiliary power circuit to the main power circuit.

(2) A combination of a.c. and d c. generators driven by the house turbine, so that the a.c. side can either deliver power to, or, acting as a motor, receive power from, the main bus bars.

(3) An a.c. house generator, with electrical connection to the main circuit through static transformers. The house turbine may serve only to carry the auxiliaries in the event of interruption of the main current supply or to help out at times of heavy load, spinning idly in a vacuum at other times. This arrangement requires a.c. motors, which for variable speed drives are more expensive and less efficient than d.c. motors.

House generator coupled to main unit.—With this arrangement the auxiliary circuits are electrically isolated from the main circuits and direct current motors can be used if desired, but in other respects it is similar to the following system:

Auxiliaries driven electrically from the main unit, with bleeder heaters. —In this arrangement the steam cycle is of high efficiency, particularly if a sufficient number of stages of feed heating be employed, and bled steam can be used in deaerators or softeners. The auxiliaries, however, are dependent upon the main unit and their operation may be interfered with by electrical disturbances in the main power circuit. Structurally, the main turbine is complicated by bleeder nozzles and sometimes there is difficulty in conveniently locating the bleed heaters, deaerators and evaporators in the neighborhood of the main turbine. However, this heat balancing method is receiving increasing attention and has been adopted in a number of large central power stations.

The division of energy to the electrical and steam-driven auxiliaries of the Lakeside, Milwaukee, pulverized-fuel station, in November, 1924, is shown in the following table. The general design of the station, which is a straight Rankine-cycle layout, is shown in the figure on page 422, which also indicates the temperature conditions and the energy consumption of the various units.

DIVISION OF ENERGY TO AUXILIARIES, LAKESIDE STATION, November, 1924

A—Electrical Auxiliaries

1 Station lighting	0 1%	
		0 10%
2 Coal handling:		
Car dumper	0 0006	
Magnetic pulley .	0 006	
Crushers	0 02	
		0.03
3 Preparation house:		
Conveying green coal. . . .	0 003	
Pulverizing	1 08	
Conveying pulverized coal...	0 025	
		1.11
4 Boiler room, estimated from tests:		
Induced draft fans	0 50	
Coal-feeder motors	0 08	
Primary air fans... . . .	0 25	
Boiler-feed pumps	0 62	
Air compressor, machine shop, etc	0 25	
		1.70
5 Turbine room:		
Circulating pumps	0 88	
Hotwell pumps	0.29	
Air removal (on one unit)	0 17	
House service and miscellaneous	0 03	
		1 37
Total energy for electrical auxiliaries....		4 31

B—Steam-Driven Auxiliaries

1 Boiler room:		
Exhaust heat reclaimed:		
Boiler-feed pumps	1 24	
Induced-draft fans (one boiler)....	0 02	
House service pump..........	0 01	
Exhaust lost:		
Steam jets on burners.....	0 01	
Boiler soot blowers..	0.2	
Economizer soot blowers......	0 43	
Superheater soot blowers...........	0.31	
Ash conveyors	0.4	
2 Turbine room:		
Steam-jet pumps	0.36	
		2.98
Less credit for heat returned to condensate....................		1.14
		1.84
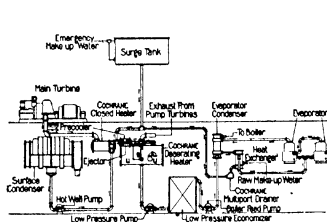
Fig. 1
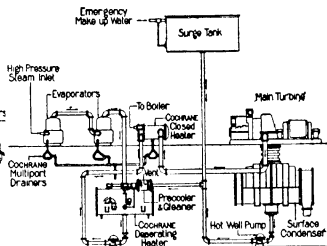
Fig. 2

Sample Heat Balance Hookups.—The heat balancing arrangements or "hookups" here described have been selected to illustrate some of the possibilities in an elementary way. Not all are suitable for any one type of plant, such as the large "base load" plant, nor are all of equal merit, as some have been dictated by existing conditions, such as apparatus already installed or space limitations, or by financial considerations, or by personal preferences, while others are to be recommended for industrial or other medium and small sized plants.

In Fig. 1 the water withdrawn from the main condenser by the hot well pump is forced through a closed heater receiving steam from a bleeder connection on the main unit, after which it passes to the deaerating heater, which is supplied with steam from turbines driving auxiliaries. The admission of water to the heater is controlled by a float operated valve, just preceding which in the water line there is a branch connection to an elevated surge tank to provide the "give and take" necessary in the system to compensate the variable water content of the boilers at different rates of steaming. A float placed low in the surge tank controls a valve in the emergency make-up water supply pipe. A pump withdraws water from the deaerator and forces it through a low pressure economizer to the boiler feed pump, by which it is pumped through the evaporator condenser and into the boilers. The distilled water from the evaporator condenser and from the steam coils of the evaporators is discharged to the surge tank. The deaerating heater is vented by a steam ejector discharging into a small vent condenser or heater combined with the pre-cooler in which the air and vapor are cooled before reaching the ejector.

The arrangement shown in Fig. 2 differs from the preceding principally in that the deaerating heater precedes the bleeder heater in the feed water circuit and receives steam from evaporators instead of from auxiliaries. For efficient deaeration it is not so good as the arrangement shown in 1, since the lower the temperature in the deaerator, the more difficult the deaeration becomes.

In Fig. 3 the deaerating heater is preceded by two bleeder heaters and is followed by a third. The amount of steam drawn from the main turbine for the second bleeder heater is controlled by a thermostatic valve according to the temperature in the deaerator, so that the latter is held constant, regardless of variations in the supply of steam from the auxiliaries, in order to maintain a constant pressure in the auxiliary exhaust line. An alternative arrangement is to place a flow valve in the exhaust

line to maintain therein a pressure slightly above atmospheric, the temperature in the deaerating heater being allowed to vary. In this hook-up both an elevated surge tank and a low level storage tank are used. The surge tank receives water from the hot well pump through a V-notch condensate meter, while another V-notch meter measures the intake of make-up water. Besides supplying water to the deaerating heater, the surge tank also provides water for oil coolers, from which the water passes to the storage tank and is returned to the surge tank by a service pump.

Fig. 4 differs from the preceding layouts in that the steam supply for the deaerating heater is drawn from a specially designed turbine in which the high and low pressure stages are separated by a solid diaphragm, so that the steam taken out from the high pressure side must pass through a flow valve in order to enter the low pressure stages. The flow valve serves to hold a fixed minimum pressure in the deaerating heater and in the heating or other low pressure steam using system supplied with bled steam. This arrangement is particularly useful in industrial plants where bled steam is used in low pressure heating systems and for other purposes. Auxiliaries also may exhaust into the low pressure piping, a steam check valve being inserted in the connection to the turbine, to prevent back flow. The deaerating heater is vented to the main condenser of the turbine, a precooler in the vent line transmitting to the inflowing cold water the heat of the steam-air mixture withdrawn from the deaerating heater.

In Fig. 5 the steam for the deaerating heater is supplied by a house turbine, but inasmuch as the load upon the latter will be relatively constant, even with wide variations in the load on the main turbine and corresponding variations in the amount of condensate to be heated, the temperature imparted to the feed water would vary widely if all of the house turbine exhaust were at all times used to heat it Where this exhaust will at times amount to more than is required for feed heating, the excess can spill over through a flow valve to a low pressure stage of the main turbine. The supply of such steam to the latter must be controlled by the main governor, and an atmospheric relief or back pressure valve should also be connected to the house turbine exhaust piping.

In Fig. 6 the deaerating heater normally receives steam from the house turbine, as in Fig. 5, but it is assumed that this supply is at times less and at other times more than required by the heater. An intermediate stage of the main turbine is therefore connected through a pressure reducing valve so that, when the steam pressure in the heater is lower than the pressure in that stage, a supplementary supply of steam will be bled from the turbine. A check valve in shunt with the pressure reducing valve and opening towards the main turbine permits reverse flow whenever the house turbine exhaust pressure is greater than the pressure in the bled stage of the main unit. In this way a continuous heat balance is maintained without waste of steam. The temperature to which the feed water is heated is never higher than the temperature of the steam in the main turbine connection and at times of heavy load, when the temperature of the feed water would otherwise tend to fall if heated only by the auxiliary turbine exhaust, it cannot drop below the limit fixed by the pressure reducing valve. The bleed connection on the main unit must be governor controlled, in order that overspeeding may not occur.

In Fig. 7, heat for the deaerating heater is supplied from a bleeder nozzle on the main turbine, but there is no direct connection between the bleeder opening and the interior of the heater, since the steam for the

latter comes from an evaporator which receives steam from the main turbine bleeder. The bleeder connection must be taken from a turbine stage having a pressure sufficiently high to provide the temperature differential needed to force the required amount of heat through the evaporator heating surface. The water is pumped from the deaerating heater through a closed heater to the economizer or boilers. This closed heater receives its steam supply from the same bleed connection as does the deaerating heater, and the boiler feed water is heated to nearly the bleed temperature, while at the same time a certain amount of evaporated make-up is obtained with-
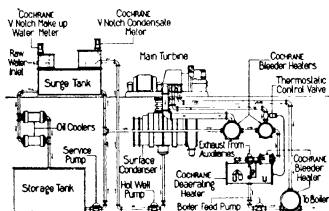
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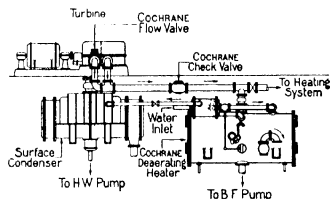
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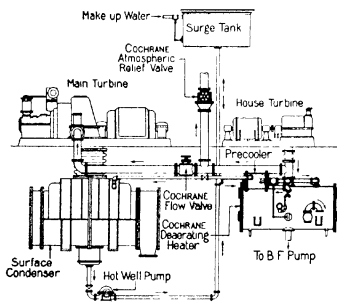
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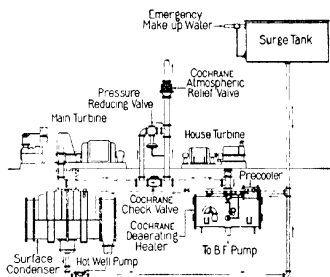
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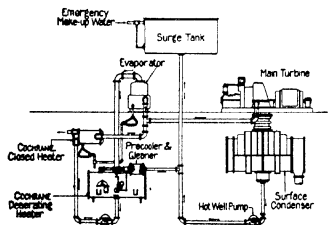
Fig. 7

Fig. 8

out loss in plant efficiency as compared with a similar plant having a single bleed heater but no evaporator. The deaerating heater serves as the condenser for the evaporator.

In Fig. 8, the main turbine is bled at three points, the low-pressure and intermediate bleed connections supplying steam to closed heaters, while the high-pressure bleed supplies a make-up evaporator, the vapor from which is utilized, together with exhaust from the turbine-driven boiler feed pumps and from the house turbine, in the deaerating heater. Steam check valves prevent back flow from the evaporator to the main turbine and from the deaerator to the main turbine, the latter being also protected by an atmospheric relief valve. Steam for the evaporator can also be taken from

HEAT CYCLE FOR STATION IN FIG 8 (Flow in Lb per Hr)

Load, Kw................	17,000	26 000	35,000	Average
Total steam to be evaporated, 300 lb throttle, 250° superheat, lb	196.540	277 800	383 800	
Steam per boiler, lb	74,870	105,830	146.200	
Average CO_2	10 5	12 0	12 75	
Coke in ash, %.......	10 5	19 5	25.0	
% carbon lost in ash...	1 57	3 36	4 64	
Temp. feed water to economizer, ° F...	222 5	235.8	241.0	
Temp. feed water to boiler, ° F...	319	322	334	
Pressure at throttle lb	300	300	300	
Pressure at boiler, lb.....	315	320	330	
Superheat. ° F	258	270	275	
BTU added in boiler...........	1062	1056	1057	
Boiler test eff., %.	76 64	76 12	73.83	75 2
Plant factor	93	95	.96	.951
Ave. coal per hr., incl. plant factor, lb .	4 29	6 00	8 39	6.7
Auxil. use, %	7	5	4	5
BTU per net Kw....................	18,520	16,580	17.030	17,200
Overall station eff., %	18 44	20.59	20.05	19.85
Boiler & econ., normal eff., %.........	77.92	78.35	77 25	77.8
Turbine water rate. no bleeding, lb.....	10.42	9.75	10.15	10.09
Water rate of plant, lb...............	12.43	11.22	11 4	11.57

Fig. 9

Fig. 10
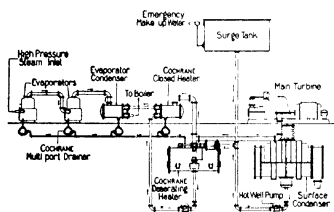
Fig. 11
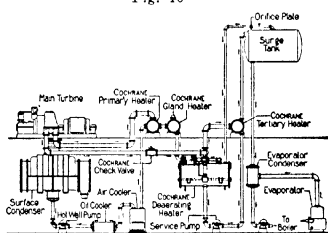
Fig. 12

the main steam headers, or the heat head on the evaporator can be increased by throttling the steam bled to the second level heater, thus reducing the temperature of the water supplied to the deaerator. The station contains two such complete power units.

In Fig. 9 the steam for the deaerating heater is supplied by a double-effect evaporator, which receives exhaust steam from auxiliaries. At times the auxiliaries will supply more heat than can be transmitted through the evaporator tube surface with the temperature head available, in which event the pressure at the inlet to the first effect will rise. A flow valve is therefore installed in a by-pass around the evaporator, so that the excess steam can spill over directly from the exhaust line to the deaerating heater. At other times when the amount of condensate is so great that the heat available in the auxiliary exhaust is not sufficient to give the desired temperature, the heater draws a supplementary supply of steam through a pressure reducing valve from a bleeder connection on the main turbine, a steam check valve protecting the latter against back flow of steam.

In Fig. 10 the deaerating heater is supplied with steam from a bleeder on the main turbine and the mixture of air and steam vented from the deaerating heater flows to a lower stage of the same turbine. A vent condenser is not required, as there is no ejector or air pump and heat available in the mixture is utilized for producing power in the main turbine. Back flow of steam from heater to turbine is prevented by a steam check valve.

out loss in plant efficiency as compared with a similar plant having a single bleed heater but no evaporator. The deaerating heater serves as the condenser for the evaporator.

In Fig. 8, the main turbine is bled at three points, the low-pressure and intermediate bleed connections supplying steam to closed heaters, while the high-pressure bleed supplies a make-up evaporator, the vapor from which is utilized, together with exhaust from the turbine-driven boiler feed pumps and from the house turbine, in the deaerating heater. Steam check valves prevent back flow from the evaporator to the main turbine and from the deaerator to the main turbine, the latter being also protected by an atmospheric relief valve. Steam for the evaporator can also be taken from

HEAT CYCLE FOR STATION IN FIG 8 (Flow in Lb per Hr)

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Total steam to be evaporated, 300 lb throttle, 250° superheat, lb	196,540	277 800	383 800	
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Coke in ash, %........	10 5	19 5	25.0	
% carbon lost in ash...	1 57	3 36	4 64	
Temp. feed water to economizer, ° F...	222 5	235.8	241.0	
Temp. feed water to boiler, ° F...	319	322	334	
Pressure at throttle lb	300	300	300	
Pressure at boiler, lb...	315	320	330	
Superheat. ° F . .. . :	258	270	275	
BTU added in boiler...........	1062	1056	1057	
Boiler test eff., %.	76 64	76 12	73.83	75 2
Plant factor	93	95	.96	.951
Ave. coal per hr., incl. plant factor, lb .	4 29	6 00	8 39	6.7
Auxil. use, %	7	5	4	5
BTU per net Kw.....................	18,520	16,580	17.030	17,200
Overall station eff., %	18 44	20.59	20.05	19.85
Boiler & econ., normal eff., %.........	77.92	78.35	77 25	77.8
Turbine water rate. no bleeding, lb.....	10.42	9.75	10.15	10.09
Water rate of plant, lb................	12.43	11.22	11 4	11.57

temperature of the bled steam. After leaving this heater the water is heated in the condenser of an evaporator which uses high pressure steam.

The arrangement shown in Fig 12 includes a deaerating heater with surface type reboiler and a closed heater, both receiving steam from the same bleed connection, as in Fig. 11. Before the water reaches the deaerating heater it has been partially heated by passing through an oil cooler, an air cooler and a primary closed heater receiving steam from a lower pressure stage of the main turbine. After leaving the closed heater following the deaerating heater, the water passes to a closed, elevated surge tank, in which a vapor pressure corresponding to the water temperature is maintained automatically by venting vapor through an orifice back to the deaerating heater. From the surge tank the water passes through the condenser of the make-up evaporator and thence to the boiler feed pump.

In Fig. 13 the main turbine is bled at three points, viz., the first or lowest pressure point to a primary jet heater and the second and third points to closed heaters. Water is pumped from the condenser hot well to an elevated closed surge tank, in which a steam blanket is maintained by a connection to the intermediate turbine bleed, the tank being vented to atmosphere. In this way ingress of air to the condensate is avoided and some of the oxygen admitted to the surge tank with the make-up water will be removed by the jet heater. To insure perfect elimination of air a deaerating heater could be substituted for the jet heater without other changes in the hook-up. A steam check valve prevents back flow from jet heater to turbine.

Fig. 14 shows a three-stage extraction layout. The intermediate heater is of the direct-contact deaerating type receiving steam from a stage just above atmospheric pressure. The make-up is shown as being introduced to the main condenser, although in the actual installation it was admitted to the surge tank.

Fig. 15 shows a feed water heating system using extracted steam from four different stages of the main unit. The lowest pressure extraction is taken into a surface heater. The next higher extraction supplies the heating and deaerating unit, consisting of a surface heater and a deaerating type heater with evaporator tubes in the water space. The next higher stage extraction is led to a surface heater. The highest pressure extraction supplies an evaporator, the vapor from which is admitted to the surface heater, which also receives steam from the next lower bleed point. In other words, the evaporator will be run at a pressure approximating that of the next to the highest bleed point on the turbine.

Fig. 16 shows bleeding from two points on the main turbine. There is also a smaller high-pressure turbine and the system contains two gland heaters, one for the high pressure turbine and one for the main turbine. A surface heater receives steam from the lowest pressure bleed on the main turbine and a deaerator and surface heater both receive steam from the high pressure bleed point on the main turbine. The make-up is admitted to the surge tank, which stores the hot water.

Fig. 17 shows a layout in which even though the turbines are large, jet condensers are used. In other words, all of the feed water is make-up. The water is really quite good, but from an operating standpoint it has been found desirable to treat it chemically in a combination hot process softener of the deaerating type. The steam supply comes from steam driven auxiliaries, with live steam make-up, if necessary.

In Fig. 18 the water from the condenser hot well is first heated by the precooler of the deaerator and by the evaporator condenser, after which it is flashed down in the deaerator and then again heated by the condenser of the house turbine, before passing to the boiler feed pump. The loss of temperature in flashing reduces the temperature head available to the evaporator, that is, were a deaerating heater used, the evaporators could exhaust directly into it and would have the benefit of a greater temperature head, assuming the boiler feed water to leave the deaerator at the same temperature in either case.

It can be said, in general, that feed water systems are laid out on the unit principle, that is, each main turbine has its own set of feed water heaters. It is hardly feasible to bleed from two turbines into one heater, as the two would rarely have the same pressure at the bled stage, which would mean that either one turbine or the other would be furnishing all of the steam with the check valve in the line from the other turbine closed off momentarily. Double unit installations of heaters have been made and in other cases cross connections with valves have been provided.

It is customary to vent *closed* stage heaters to the steam space of the next lower heater, the lowest pressure heater being vented to condenser. Where the drips also are permitted to follow this course, there is a certain degradation of heat, that is, the drips flash in the lower heater and prevent the bleeding of an equal amount of steam at that point, although from the thermodynamic point of view all heat imparted to feed water should be drawn from the turbine at the lowest possible temperature, and it is of course wasteful to throw heat away in the condenser if it can be avoided. This disadvantage has been overcome in some cases by the use of heat exchangers and in others by pumping the drips from each heater into the feed line following that heater. The drainage may be controlled by inverted syphons or U-bends, or by drainers, the latter being preferable as occupying much less space and as being more reliable. The water seals in U-bends are sometimes blown due to flashing of the hot water in the ascending leg of the U, the resulting mixed column of water and steam bubbles not being heavy enough to withstand the pressure differential.

The Weir Heat Regeneration System, Fig. 19, comprises a low-pressure boiler at approximately atmospheric pressure, situated in the uptake of the main boiler. The feed water is delivered from the condenser, through a L.P. heater supplied with exhaust from the main feed pumps, to this low-pressure boiler, which also acts as a feed reservoir and pump supply for the main boiler. The steam generated by the low-pressure boiler is used partly in the low-pressure stages of the main turbine, and partly for producing makeup in a low-pressure evaporator, the makeup vapor and drips passing to the main condenser. The water withdrawn from the low-pressure boiler passes through a high-pressure feed heater supplied with steam bled from the main turbine to the high-pressure boiler.

FIG. 19—WEIR HEAT REGENERATION SYSTEM—*Power*

FIG. 20—MULTISTAGE HEATING WITH ECONOMIZER BETWEEN HIGH
AND LOW PRESSURE STAGES

a Main turbine	*e, f, g* Closed heaters
b Auxiliary turbine	*h* High temperature surge tank
c Main condenser	*i* Economizer
d Auxiliary condenser (first heater)	—*Z. d. V. deut. Ingr.*

In Fig. 20 the economizer i receives water from the high-temperature surge tank h, which collects the entire condensate and the water which has been heated by bled steam in two stages d and e. From the economizer the water passes through two more bleed heaters f and g to the boiler.

In the Cahokia station, Fig. 21, condensate passes through air and oil coolers, evaporator condenser, and a low pressure heater, to a Cochrane surface type deaerating unit, consisting of a high-velocity intermediate pressure closed heater and the deaerating heater proper, both receiving steam in parallel from the same intermediate-pressure stage of the turbine. The water is then forced by the boiler feed pump through the high pressure stage to the boilers.

In the Big Sioux Station, Fig. 23, the condensate pumps take their suction from the condenser hot wells and pump through the bleeder heaters and inter- and after-coolers directly to the suction of the boiler feed pumps, which deliver through the high-heat-level condenser of the evaporator system to the boilers. The discharge from the boiler feed pumps is controlled by varying the head on their suction, by means of the speed of the condensate pumps.

FIG. 21—CAHOKIA STATION—*Power*

FIG. 22—CHARLOTTENBURG STATION

a	New boilers	i	Jet condenser
b	Economizer	k	Bridgewall
c	Surge tanks	l	Closed surge tank
d	Old boilers	m	16.000-Kw. generator
e	Jet heater	n	Condenser
f	6900-Kw. generator		$t/h =$ metric tons (2200 lb.) per hr.
g	Heating coils		$at =$ atmospheres
h	Evaporator		—Z d V dent. Ingr.

    In the Charlottenburg Station, Fig. 22, the new boilers a furnish steam at 32 atmospheres (470 lb. gage) and 400° C. (752° F.), to the high-pressure 6900-Kw. turbine, the high-pressure end of which exhausts part of the steam to the low pressure header at 13 atmospheres (191 lb. gage). The low pressure end of the same turbine supplies steam to the makeup water evaporator h and to heating coils g. Steam from the old boilers d, supplemented by the steam from the high-pressure end of the first turbine, passes to the 16,000-Kw. turbine. The condensate is circulated through the furnace bridge wall k, and passes to jet condenser i, where it condenses the make-up vapor from evaporator h. The water from the jet condenser i, with drips from the evaporator h and condensate from heating coils g, is led to closed surge tank l, where the mixture reaches a temperature of 80° C. (176° F.). It is withdrawn from the tank and passes to jet heater e, where it is heated to 160° C. (320° F.) by steam at 191 lb. gage from the first turbine, and goes finally to surge tank c, from which the boiler feed pumps send it to the flue gas economizer b of the high-pressure boiler.

FIG. 23—BIG SIOUX STATION—*Power Plant Engg.*

FIG. 24—COLUMBIA STATION—*Power Plant Engg.*

In the Columbia Station, Cincinnati, Fig. 24, steam is received at 565 lb. abs., 725° F., from the three normal boilers and one reheat boiler. Between the H.P. and I.P. stages it is brought again to 725° F. in an inter-stage reheater K located in the reheat boiler. The condensate passes through the generator air cooler A, L.P. open extraction heater C, closed L.P. extraction heater E, gland steam condenser F, deaerator vapor condenser G, entering

FIG 25—G E TURBINE UNIT, CRAWFORD AVE. STATION

H.P. element, 17,000 Kw , receives steam at 565 lb. abs. 725° F., exhausts at 120 lb. abs., 412° F. Reheated to 725° F., 110 lb abs., for L P. element, 43,000 Kw., exhausted at 0 5 lb abs

H.P. extraction heater E receives steam at 33 lb abs , delivers water 210° F.
I.P extraction heater C receives steam at 10 25 lb. abs
L.P. extraction heater B receives steam at 3 4 lb abs.

A—Ejector steam condenser.
D—De-aerator vapor condenser.
F—De-aerator.

G—Motor-driven condensate pump.
H—Motor-driven feed pump.
          —*Elec. World.*

the open H.P. extraction heater H at 210° F., where it is heated to 240° F., and then flashed down to 215°F. in deaerator separator and storage tank I, at which reduced temperature it is received by the boiler feed pumps J and sent to the economizer.

In each of the three compound turbine units at the Crawford Avenue Station, Figs. 25, 26 and 29, steam from four boilers (p. 581), at 550 lb. gage, is used in the high-pressure element, exhausted to a reheat boiler, and reheated for use in the lower stages, which are provided with 2-pass surface condensers, while steam for heating feed water is extracted from three or four points on the turbines. The temperature relations in each individual unit are shown in the three drawings.

In the plant shown in Fig. 27, the condensate traverses low pressure and high pressure heaters supplied with steam bled from turbine stages, then goes to a Cochrane deaerating heater, which also serves as a surge tank. If the level becomes too high in the heater the excess water spills into the condensate storage pump, which is also connected to the condenser

FIG. 26—PARSONS TURBINE UNIT, CRAWFORD AVE STATION

H.P. element, 15,500 Kw., receives steam at 565 lb. abs., 725° F., exhausts at 115 lb. abs., 430° F.   Reheated to 700° F., 105 lb. abs., for I.P. element, 28,500 Kw. Exhausted at 2 lb. abs. to L.P. element, 6000 Kw.

H.P. extraction heater F receives steam at 115 lb. abs., delivers water 315° F.
I.P. extraction heater E receives steam at 20 lb. abs.
L.P. extraction heater C receives steam at 5 lb. abs.
Booster pump heater D receives steam at 15 lb. abs.

A—Ejector steam condenser.
B—Drain cooler
G—Overflow relief valve.
H—Make-up admission valve.
I, J, K—Drainage traps.

L—Motor-driven feed pump.
M—Steam-driven booster pump
N—Standby steam-driven feed pump.
O—Motor-driven condensate pump
—Elec. World.

FIG. 27

FIG. 28—(P. 702)

FIG. 29—WESTINGHOUSE TURBINE UNIT, CRAWFORD AVENUE STATION

H P. element receives steam at 565 lb abs, 725° F., exhausts at 132 lb. abs., 450° F. Reheated to 700° F., 122 lb. abs., for I.P. element.

H.P. and I.P. element tandem-compounded, 30,000 Kw. Exhausted at 16.5 lb. abs. to L.P. element, 20,000 Kw.

H.P. extraction heater E receives steam at 50 3 lb. abs., delivers water 210° F.

I.P. extraction heater C receives steam at 17.3 lb. abs.

L.P. extraction heater B receives steam at 3.95 lb. abs.

A—Motor-driven condensate pump.   F—De-aerator.
D—De-aerator vapor condenser.   G—Motor-driven feed pump.

—*Elec. World.*

hot well. Makeup water passes through a special heater, supplied with high pressure steam, to an evaporator in which it is vaporized, the vapor passing into the high pressure bleed line which supplies the deaerating heater and also a heating system.

In the Kearny Station, Fig. 30, steam is bled from four stages of each of the five main units. The condensate passes in turn through a L.P. closed heater, a Cochrane jet heater acting as a barometric condenser, a Cochrane open deaerating heater equipped with V-notch meter, an I.P. closed heater and a H.P. closed heater. Under average conditions the temperature of the water in the open heater would be below 210° F., if dependence were placed solely on the steam from the third bleeding connection, but there are auxiliary connections with reducing valves, from bleeding points at higher pressures, from which additional steam can be taken so that the temperature can be kept up to the 212° F. required for venting oxygen to atmosphere. This arrangement permits the use of a common feed-pump suction header, and also permits the pressure on the bleeding connections to vary in any manner without affecting the operation of the feed pumps.

FIG. 30 — KEARNY STATION — *Power*

FIG. 31 — LONG BEACH STATION — *Natl. Engr.*

In the Long Beach Station, Fig. 31, the 20-stage turbines receive steam at 350 lb. gage, 264° F. superheat, and exhaust to condenser at 1½ lb. abs., with bleeding from the 11th, 15th and 18th stages. All makeup water is furnished by submerged-type, double-effect, low-heat-level evaporators, one for each unit, supplied with steam from the 15th stage. When operating on the extraction cycle, the condensate passes in succession through the inter-cooler of the air ejectors, the 18th-stage heater, the 18th-stage heat exchanger, the evaporator condenser, the after condenser of the air jets, the gland steam condenser, the deaerator condenser, the Cochrane deaerating heater, the 11th-stage heat exchanger, and 11th-stage heater to the boiler feed pumps. The closed "gland heater" takes the steam leaking from turbine glands. The auxiliary steam line is protected by a back pressure valve, while a flow valve between the back pressure valve and the deaerating heater admits steam to the latter only when there is an excess in auxiliary line. In case the pressure of the bled steam becomes higher than the auxiliary steam pressure, the flow valve prevents the bled steam from escaping into the auxiliary steam line.

FIG. 32—HEAT CYCLE AT TECUMSEH, FOR 1¼ LOAD—
Power Plant Engg.

At the Tecumseh Power Station of the Kansas Power & Light Co., Fig. 32, the hot well pumps deliver the turbine condensate through the evaporator condenser to the Cochrane direct contact deaerating heater from which the boiler feed pumps force it through the economizer to the boiler. The evaporator receives part of the exhaust of the house turbine, the remainder being utilized in the deaerating heater.

FIG 33—NEOSHO PLANT —*Power Plant Engg*

In the Neosho plant, Fig 33, makeup water first enters an open heater which is supplied with steam or vapor through a thermostatic control valve from the second effect evaporator. A pump removes the water from the heater and forces it to either the first or second effect evaporator. Live steam is reduced in pressure, passed through a desuperheater and then enters the heating coils of the first effect. The condensed steam drains off to a receiver. The vapor from the first effect passes over to the heating coils of the second effect and the condensed vapor drains off to the receiver previously mentioned. Vapor from the second effect passes to a closed heater and is condensed, the condensate passing on to the receiver. From the receiver, the water is discharged into another storage tank, shown at X, from which the boiler feed pumps draw water and force it through the closed heater, just mentioned, and to the boilers. Water for desuperheating is taken from the boiler feed line. Two bleeder connections are made to the turbine. The high pressure connection goes to the closed heater A, the condensate draining to closed heater B. Another steam connection is made to heater A from the auxiliary exhaust line, which is fitted with an atmospheric relief valve. The low pressure bleeder connection is made to heater B, the condensate being removed by a pump and discharged into the water line between heaters A and B. Water from the hot well is pumped through an oil cooler, then through the condenser for the steam jet air pump, then through the heaters B and A, and is finally discharged into the tank X, where it is mixed with the makeup water. Condensate from the air pump condenser flows through the hot well, where it is mixed with the condensate from the main condenser.

FIG. 34—PHILO STATION—*Elec. World*

The above shows calculated heat-flow in the Philo Station, Fig. 34, in which the 19-stage 35,000 Kw. turbines were designed to receive steam at 530 lb. gage, 725° F., with provision for extraction and reheating to 725° F. between the 7th and 8th stages, and extraction at the 12th and 16th stages for feed water heating. By operating the turbines as 40,000 Kw. 95% power-factor units, it was found possible to operate for one month on 14,300 *BTU* per Kw. hr.

For 35,000 Kw output per unit of 1 turbine 3 standard boilers and 1 reheat boiler, each boiler 14 086 sq ft, economizer 8837 sq ft, boiler and economizer efficiency 82%.

Heat content of steam at throttle, 1,365.6 *BTU*
Heat content per lb. added in reheat, 133.1 *BTU*.
Heat content per lb. in turbine exhaust, 985 7 *BTU*.

		With Evaporator	Without Evaporator
Temperature at *A*, ° F		75	75
B		85	85
C		97	97
D		122	97
E		162	163
F		187	188
G		205	206
H		212	212
Amount of 6 lb. extraction, lb. per hr		10,500	16,650
Amount of 33 lb. extraction, lb.		.....	1,600
Amount exhaust. lb		11,100	.....
BTU per Kw.-hr. generated		13,262	12,887
Auxiliary power		487	610
BTU per Kw.-hr. sent out		13,490	13,497
Operating efficiency ratio		0.90	0.90
Operating *BTU* per Kw -hr		15,277	14,997
Water rate with reheat, 7.66 lb. per Kw.-hr.			
Water rate as operated, lb. per Kw.-hr.		7.74	7.80

Auxiliary Power in Kilowatts

Circulating pump	420	Service pump	50
Condenser auxiliaries	150	Coal handling	75
Induced draft fans	400	Miscellaneous and lighting	25
Forced draft fans	125		
Stoker motors	18	Total	1,288
Air washer	25	Boiler feed pump	372
		Total	1,660

FIG. 35.—PARR SHOALS STATION—*Southern Engr*
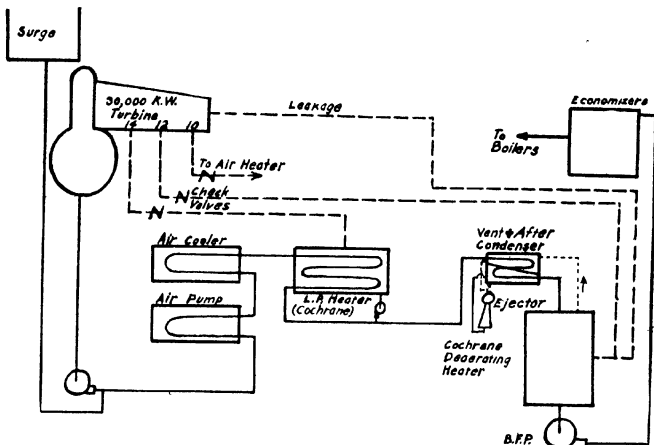
FIG 36

The Parr Shoals Station, Fig. 35, although a "standby" plant for use in connection with a hydroelectric system, was designed for operation at high efficiency, using pulverized coal. The condensate from the condenser hot well is passed through the inter- and after-condensers of the air ejector equipment and through a Cochrane closed heater supplied with steam bled from the main turbine, and then to a Cochrane deaerating heater, where it and the make-up water are heated and the oxygen driven off, for the protection of the steel economizers. The deaerating heater is of jet tray type combined with surge tank. Automatic thermal control of the dual drive of the circulating pumps holds a constant water temperature of 215° F. The diagram shows the heat balance when the turbine is operated at its full load, 12,500 Kw.

In Fig. 36, steam is bled from the 14th stage of the turbine to a Cochrane closed heater, and from the 12th stage to a Cochrane deaerating heater, which also receives gland leakage, while an air heater is supplied with steam bled from the 10th stage. The condensate passes through the cooler of the steam jet air pump, through the generator-air cooler, the low pressure closed heater, the deaerating heater, and economizers, to the boilers. The deaerating heater is equipped with steam jet ejector and combination vent- and after-condenser in one shell for vacuum operation.

In the station shown in Fig. 28, page 695, condensate and makeup are heated by steam from the house turbine, in a Cochrane deaerating heater. The deaerator can be operated above or below atmospheric pressure, a thermostat turning on steam to the steam jet air pump whenever the pressure in the deaerating heater descends to near atmospheric pressure.
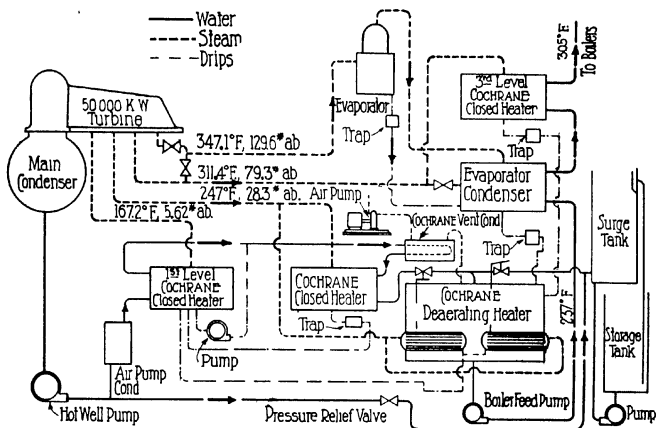
FIG. 37—RICHMOND STATION

In the Richmond Station of the Philadelphia Electric Co., Fig. 37, steam reaches the turbine at an average temperature of 675° F., 375 lb. gage, while the condensate is heated in three levels to a final temperature of 305° F., the first level being in a Cochrane closed heater receiving steam bled at 5.6 lb. abs. from the 18th turbine stage. The second level of bleeder heating, which also includes deaeration of the water, is accomplished by a Cochrane closed heater and a Cochrane deaerating heater, both receiving bled steam at 28.3 lb. abs. from the 15th stage. The water is withdrawn from the deaerator at 237° F. by the boiler feed pump and is then forced through the condenser of the makeup water evaporator. The evaporator can take steam either from the high-pressure (10th stage) bleed point at 129.6 lb. abs., when excessive makeup is required, or from the 12th stage at 79.3 lb. The condensate and makeup then pass to the boiler through a Cochrane closed heater at boiler pressure. E. L. Hopping states that although the entire system is closed and should not permit the entrance of any excessive amount of oxygen, it was felt that the deaerating unit should be provided, to remove oxygen leaking in through packing glands, etc., for the protection of steel economizer tubes. Connections are provided so that two units can operate through a single deaerator if necessary. Storage tanks are provided into which all excess water overflows from the surge tanks. In case a boiler is to be emptied, the water is drained to one of the tanks and after being allowed to settle, used again, reducing the evaporator load. The pumps taking water from these storage tanks are automatically controlled to discharge water into the system whenever the water reaches a certain predetermined low level in the surge tanks.

227,000 lb/hr boiler feed

205°

1210 lb/hr Spray water
358°-1490 lb abs-863-1193   330
14,300 lb/hr   Separator

400 lb gage -700°F
220,925 lb/hr Boiler steam
H=1287   S in X
Des   4" 13,090 lb/hr

340 lb/hr spray water

1st Stage Heater
298°   q=319   348°
4 in

6075 lb/hr vapor

-1177
294°-613 lb abs 94%
7300 lb/hr   Des
Separator   12 in

6960 lb/hr
94° S
H=1226
Turbine
98 8 %
940 %

(805/1,000)
(631/1,000)
(386/1,000)
(174/1,000)

85°   Evap

Economizer
212° -147 lb abs

3rd Stage Heater
15015 lb/hr
q=176   212°
208°

Ht of Total
vapor   Ht   Ht hg
-958 -1150 -180

6680 lb/hr
1/2 in   85°F
6075 lb/hr raw water
3 in
7300 lb/hr

148°-354 lb abs
9420 lb/hr
q=114   148°

- 948 -1064 -116   14 in
7420 lb/hr

6 in   146°
41,775 lb/hr drains

228,550 lb/hr

Surge Tank

Main Condenser
28 in Vacuum

FIG. 38—RIVERSIDE STATION—Power

    The above figure shows the heat-cycle, at 20,000-Kw. load, for Riverside Station, Fig. 38. The first bleeder line, taken from the turbine at a point below the impulse blading, supplies the 1st-stage closed heater through a desuperheater, and on occasion supplies the evaporator, which, however, is normally supplied through the 2nd-stage bleeder and desuperheater. The 3rd and 4th-stage bleeders supply the corresponding heaters, the vacuum on the 4th-stage heater being maintained by a small line to the main condenser. Each heater is drained to the hot well of the succeeding heater and provision is made for the flash to enter the supply to this heater. The total condensate from the heater system passes to the hot well of the 4th-stage heater and from here is drawn to the hot well of the main condenser to flash it and remove any air entrained during the cycle. The condensate pump then bypasses the feed through the generator air cooler, the inter- and after-condensers of the air ejectors and the 4th and 3rd-stage heaters to the feed pump suction. If the supply is greater than the boiler feed pumps will take, the condensate backs up into the surge tank. Raw water for house service and boiler makeup is supplied through lines from the condenser intake. The service water entering the evaporator under float control is first passed through the bearing-oil coolers. Vapor from the evaporator and the drainage pass to the 3rd-stage heater, which operates at atmospheric pressure for this load.
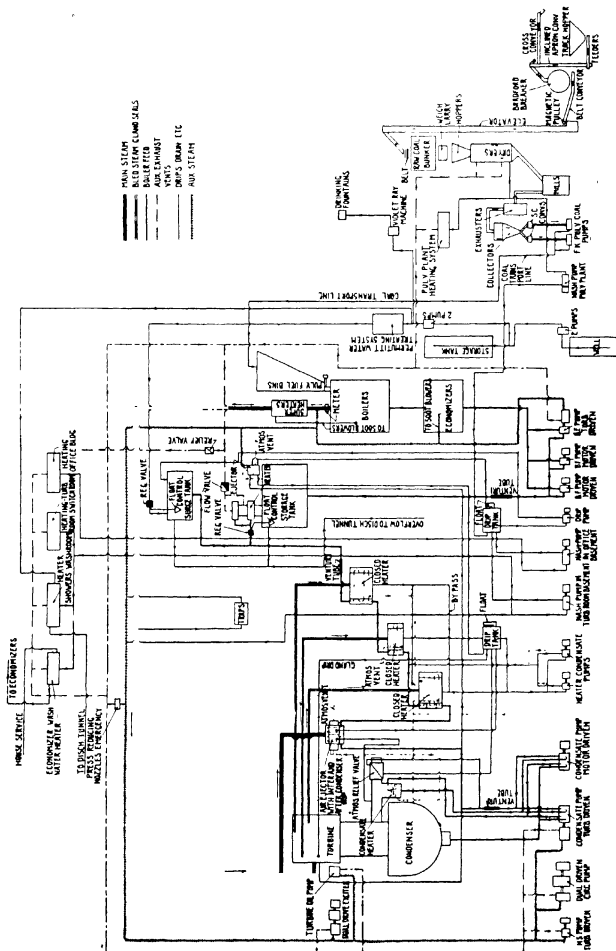
FIG. 39—SUSQUEHANNA RIVER STATION—*Power Plant Engg.*

In the Susquehanna River Station, Middletown, Pa., Figs. 39. and 40, (also p. 427), steam from the 10th stage of a 17-stage, 30,000-Kw. turbine is used in a 2-effect evaporator to prepare the makeup feed water, which together with the condensate, goes to a Cochrane Jet Heater. From the 13th stage, steam is bled to No 3 closed heater, vented to No. 1 closed heater. The 15th stage is bled to No. 1 heater, vented to condenser. Steam from turbine packing gland is used in No. 2 closed heater. vented to No. 1. Steam for the air ejectors on condenser is taken from auxiliary piping, reduced to 135 lb. pressure, the non-condensable gases going to atmosphere and the condensed steam to hot well. Condensate pump takes water from hot well and delivers it through ejector condenser to No. 1 heater, then main condensate is joined by condensate from the three closed heaters and passes successively through gland heater, No. 3 heater and the jet heater, where it is heated to 212° F. by exciter-turbine exhaust and passes to boiler feed pumps, economizers and boilers. Aside from radiation, the only heat loss is through the condenser circulating water and the air discharged by the ejectors. This station has under test shown a fuel consumption of only 1.1 lb. coal per Kw. hr., and for March, 1925, the total consumption per Kw. hr. net output was 1 233 lb. coal, or 16,615 BTU. It is planned to use bituminous coal with anthracite from the river bed.
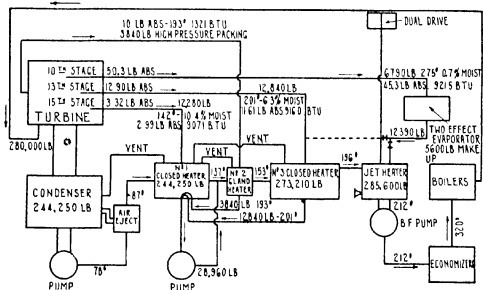
FIG. 40—SUSQUEHANNA RIVER STATION. HEAT FLOW AT 26,720 KW. LOAD (See page 705)

In the Seal Beach Station, Figs. 41 and 42, steam from oil-fired boilers enters the turbines at 375 lb. gage and 700° F. total temperature, and is extracted at four points as follows:

1st bleeder, 3.67 lb. abs., 95.1% quality, 1075.7 BTU per lb.
2nd bleeder, 14.55 lb. abs., 99.77% quality, 1147.3 BTU per lb.
3rd bleeder, 58 0 lb abs., 109° F. superheat, 1231.2 BTU per lb.
4th bleeder, 170 0 lb. abs., 208° F. superheat, 1307.1 BTU per lb.

Condensate passes from the hot well pumps through coolers for generator air, transformers and bearing oil, and through the inter- and after-coolers of the steam-jet air ejectors, to the 1st heater. Normally the evaporators distill the entire makeup, taking steam from the No. 3 bleed point and passing the vapor to No. 2 heater, where it is condensed and passes with the drains into the steam space of No. 1 heater and is pumped into the condensate flow along with the drains from this heater. Boiler feed pumps feed through Nos. 3 and 4 heaters to the main boiler feed header.

FIG. 39—SUSQUEHANNA RIVER STATION—*Power Plant Engg.*

FIG. 43—VALMONT STATION—*Power Plant Engg.*

In the Valmont Station, near Denver, Fig. 43, steam is bled from three points to heat the feed water up to 300° F. Surge tanks are provided so that water can be stored or used at times of sudden load changes. Condensate is pumped directly from the condenser hot well to the high-level surge tank, which also receives all make-up water and all other condensate which may have been used for cooling purposes or collected as drips. Water as required by the boiler room flows from this tank and passes first through the air ejectors and then through the 140° F. and the 200° F. bleed heaters. The latter serves as a regulating heater under the control of a thermostat in the deaerator to maintain a uniform temperature of 206° F. Boiler feed pumps draw upon the stored deaerated water in the deaerator and pump through the 55-lb bleed heater and then to the boiler units. The feed pumps are steam driven, while all other auxiliary equipment is normally electrically driven.

FIG. 44—WAUKEGAN STATION—*Power*

Fig. 44 shows the heat balance diagram for the Waukegan plant of the Public Service Company of Northern Illinois for the condition of full load on the turbine. Steam is bled at four points to heat feed water in three closed heaters and one open heater serving a flash deaerator. In the latter, the temperature of the water is dropped from 240° F. to 215° F., resulting in a certain increase in fuel consumption due to loss in heat availability. When operating at full load the water enters the boilers at 375° F., the final 110° being gained in the economizer.

In Fig. 45 is shown the flow diagram and circuits of steam, raw water, condensate and exhaust of the Neches Station. Distilled make-up water is drawn from a storage tank directly to the condenser hot well by the vacuum in the latter. The condenser pumps deliver the main turbine condensate, together with make-up, through two closed heaters, receiving extracted steam from the low pressure end of the main turbine.

FIG. 45—NECHES STATION—*Power Plant Engg.*

From these heaters the water passes to a Cochrane deaerating heater of the direct contact type by way of the vent condenser of the latter. The deaerating heater is mounted on a cast iron surge tank, from which the boiler feed pumps take their supply. Steam is supplied to the deaerator at a few pounds above atmospheric pressure by an evaporator, and in the form of drips from two high pressure closed feed water heaters and from the main and auxiliary steam systems, or automatically through a reducing valve from the next to the highest bleed point on the main turbine, if these supplies should be insufficient. The boiler feed pumps deliver through two closed heaters which receive steam from the high pressure end of the turbine. In an emergency they can draw directly from the distilled water tank. The evaporator has two shells and can be operated as either a single or a double effect from either of the high pressure bleed points.
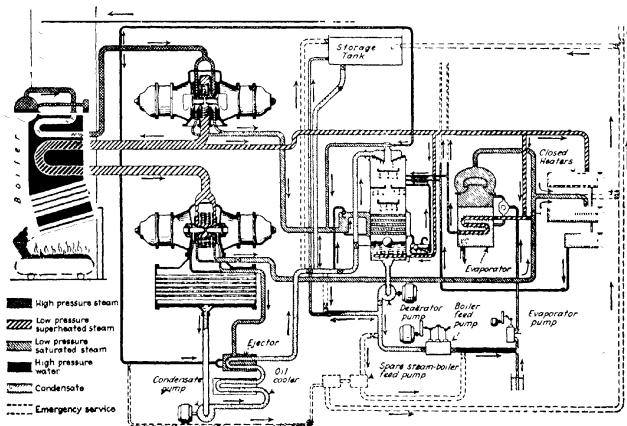
FIG. 46—COTTLANDS POWER PLANT—*Power*

Fig. 46 shows the steam and water cycles at the Cottlands (Sweden) Power Station, where the boiler feed water is heated in three closed heaters, an open deaerator and an economizer. The closed heaters receive steam bled from between the high and low pressure turbine units and from the overload chamber of the low pressure unit. The condensate, after being slightly heated in the oil cooler and air ejector condenser, is sprayed into the deaerator, wherein a vacuum is maintained by a steam ejector. The exhaust from the ejector, together with steam bled from the high-pressure turbine, is used in submerged tubes to boil the water in the deaerator, the drips from these coils being collected in a vented tank and returned to the deaerator. Make-up is supplied by an evaporator which receives steam bled from between the high and low pressure turbines, the vapor produced being condensed in one of the closed heaters.
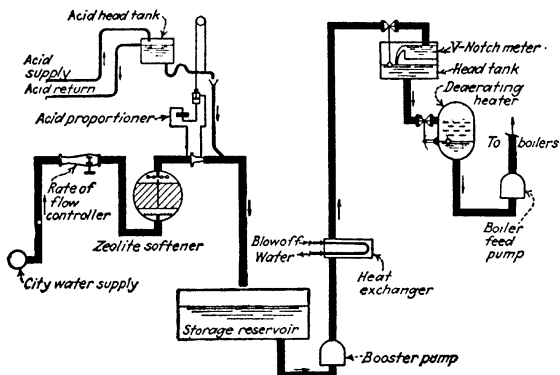
FIG. 47—BEACON ST. HEATING PLANT—*Power*

At the Beacon St. Station of the Detroit Edison Co., Fig. 47, the feed water, taken from the city mains, is first softened in a zeolite softener, then treated with sulphuric acid to correct carbonate alkalinity and finally degasified in a Cochrane deaerating heater to prevent carbon dioxide and oxygen corrosion. A continuous blow-off is employed to prevent over-concentration of dissolved salts in the boiler, the heat of the blow-off water being recovered by means of a separating tank from which vapor passes to the exhaust header and a surface heat exchanger through which the cold feed water passes.
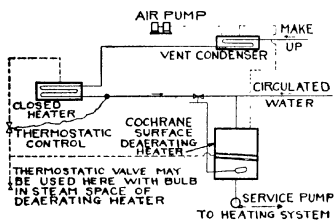
FIG. 48—WESTINGHOUSE HIGH
          SCHOOL
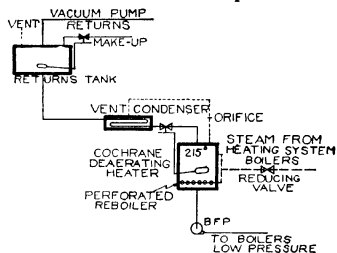
FIG. 49—HUGHES HIGH SCHOOL
          (P. 715)

At the Westinghouse High School, Fig. 48, the circulated water from the hot water heating system is returned to a Cochrane surface-type deaerating heater, where it is deaerated by live steam from a low-pressure boiler, affording protection to the piping. Makeup water enters through a vent condenser and a closed heater receiving live steam. A thermostatic bulb placed in the outlet connection of the closed heater operates a thermostatic valve in the live-steam line to the closed heater, making it possible to fix an upper limit for the temperature of the hot water. A valve could be used with bulb in the steam space of the deaerating heater.

In industrial plants the requirements for hot water and the supply of exhaust steam do not always, in fact rarely, synchronize. The steam supply may be fairly regular but the demands for hot water intermittent, as in paper mills, dyeing establishments, laundries, etc., or the use of hot water may be continuous while the supply of exhaust steam is highly irregular, as from steam hammers, water gas blowers or rolling mill engines. A constant supply of hot water can, however, be insured by providing storage, as in Fig. 50. The heater is placed over the storage tank and is fitted with a relief valve, so that back pressure can be carried. Water is admitted to the heater through two branch pipes, one of which, controlled by a valve connected to a float near the bottom of the storage tank, insures a supply of water for boiler feed requirements regardless of steam supply. The other branch has two valves, one of which is automatically opened as the steam pressure in the heater rises, thus admitting water to be heated whenever there is steam available. The second valve in this branch is connected to a float placed at a high level in the storage tank and shuts off the water when the tank is full.
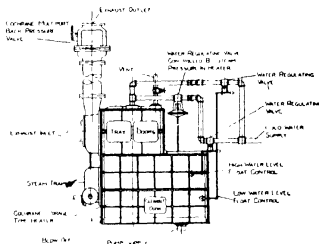
Fig. 50

Warren L. Berry presents a method of studying the probable distribution of steam in an isolated plant, based on metered consumption of steam and electricity in an existing building in which both of these commodities are purchased. A day was chosen in each month which represented average temperature conditions for the month, according to long-term Weather Bureau records, and charts such as A, B and C were plotted. The dashed curves represent the rates of generating high-pressure steam which would be required to operate a non-condensing engine carrying the recorded electrical load, and hence also the weight of exhaust steam which would be available for heating, while the solid curves represent the known rate of utilization of low-pressure steam for heating. It is seen that a portion of the steam required for heating would have to come directly from the boilers without passing through the engine, especially during the morning, when the building is heating up, while exhaust steam is wasted whenever the lighting load exceeds the heating load.

By totaling the figures for the twelve months, it was found that 32% of the exhaust steam would be usefully employed in the heating system and 68% wasted to atmosphere, and that of the steam used for heating purposes 65% would be supplied by exhaust steam, and 35% as live steam from the boiler.

DISTRIBUTION OF LOW-PRESSURE STEAM FOR EACH MONTH, USING THE DAILY NORMAL AVERAGE TEMPERATURE FOR EACH PARTICULAR MONTH

Month	Total Available Exhaust	Exhaust Steam Used	Exhaust Steam Wasted	Live Steam Used	Total Heating Steam
October	3,729,300	694,400	3,034,900	356,500	1,050,900
November	3,703,500	2,346,600	1,356,900	791,400	3,138,000
December	4,475,160	3,353,425	1,121,735	1,364,310	5,753,600

January	3,813,000	3,289,720	523,280	2,463,880	4,717,735
February	3,246,600	2,198,280	1,048,320	1,718,920	3,917,200
March	3,791,610	2,355,566	1,436,044	824,662	3,180,228
April	3,648,000	703,500	2,944,500	355,200	1,058,700
May	3,782,000	. ...	3,782,000	....	....
June	4,218,000	.. ..	4,218,000	....	....
July	4,161,750	....	4,161,750	....	... .
August	3,933,900	. ...	3,933,900	....	....
September	3,825,000	.. ..	3,825,000	....	....
Total, lb.					
per yr.	46,327,820	14,941,491	31,386,329	7,874,872	22,816,363

At 5 lb. evaporation per lb. coal burned, the coal consumed would be distributed as follows:

	Tons per Year	%
Coal for live steam heating.........	787.5	12.6
Coal for exhaust steam heating.....	1494.1	24.0
Total coal chargeable to heating.....	2281.6	36.6
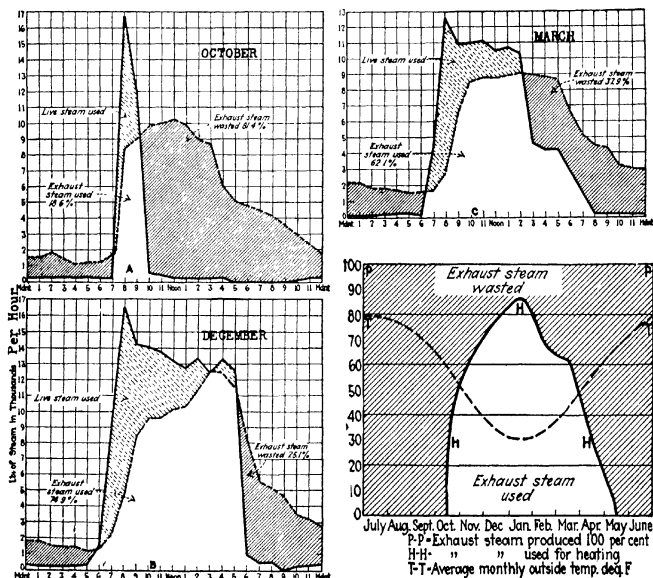
A, B, C. AVERAGE STEAM HEATING
REQUIREMENTS AND WASTE
OF EXHAUST STEAM.

D. MONTHLY VARIATION IN EX-
HAUST STEAM UTILIZATION
—Elec. World.

Fig. 51

Coal for exhaust steam wasted....... . ... 3138.6   50.3
Coal for generation (deduced) 817.5   13.1

    Total coal chargeable to power 3956.1   63.4

    In Fig. D, the curve *IIIIII* represents the percentage of the exhaust steam used, at different times of the year, and *TT* the average outdoor temperature, in ° F.

    At the Hughes High School, Fig. 49, the vacuum pump returns from the low pressure heating system pass to a Cochrane deaerating heater. This is fed with steam from the heating system boilers and serves to protect the boiler tubes from oxygen

    In the plant shown in Fig 52, condensate from two turbines passes through inter- and after-ejector condensers, to a single vent condenser, then divides to two sets of low-pressure and high-pressure heaters, and reunites in a Cochrane deaerating heater, from which the boiler feed pump draws. A storage tank receives condensate from old units and the overflow from the two-turbine system. If the water level in the deaerating heater falls too low, a float located therein opens a valve in the line from this storage tank, and permits a pump, which is always running, to supply water from the tank to the system Each turbine is bled at two points, supplying steam for its own low-pressure and high-pressure heaters, while check valves in lines to the deaerating heater permit the latter to draw from either one or both of the high-pressure bleed lines, according to the relative pressures therein.
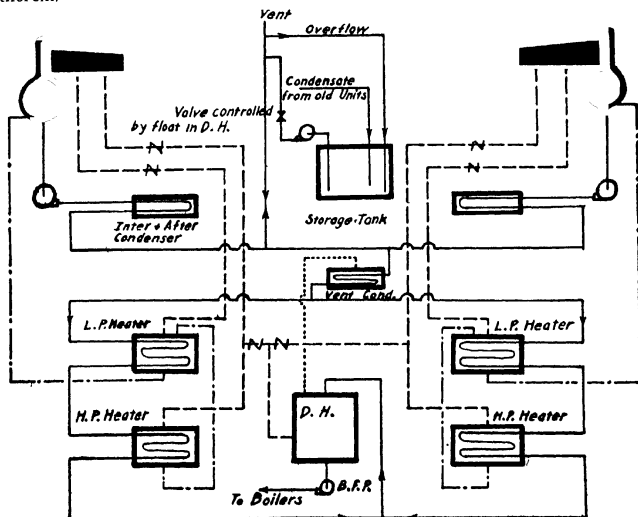
FIG. 52

BOILER SCALE AND ITS PREVENTION

Reports of boiler inspection and insurance companies show that more than half of the boilers inspected by them are affected by burned plates, defective tubes, leakage around tubes, leakage at joints, incrustation and scale, internal grooving and internal corrosion, all of which can positively be traced to the feed water. An amount of scale which is harmless at gentle rates of steaming becomes dangerous when the boilers are driven so hard that the layer of scale next to the metal is dried out, becoming an excellent heat insulator and exposing the metal to overheating and burning.

The rise in temperature of the metal, due to coatings of scale, is shown in the adjoining chart, after *E. Reutlinger.* For a clean heating surface the average value of *L*, the coefficient of transmission per sq. ft. per hr. per degree difference between metal and water, was 166, and for a surface covered with scale coating No. II, $L = 67$. This coating consisted of a layer 0.217 in. thick, of a material having a conductivity of 23.85 BTU per sq. ft. per hr. per ° F. difference for 1 in. thickness, or a layer 0.075 in. thick of a material with a conductivity of 8.06. In either case, the net conductivity of the layer of the thickness stated was 109 BTU per sq. ft. per hr. per ° F., and *L*, the coefficient of transmission from metal to water, was

EFFECT OF SCALE AND RATE OF DRIVING ON BOILER TUBE TEMPERATURE

$$\frac{1}{1/166 + 1/109} = 67.$$ Coating No. III consisted of a 0.217 in. layer of scale of 8.06 conductivity, or a 0.0217 in. film of grease of 0.806 conductivity, the net conductivity of either being 37, and

$$L = \frac{1}{1/166 + 1/37} = 31.$$ The value of *L* for a surface covered with a heavy grease coating was 13.4.
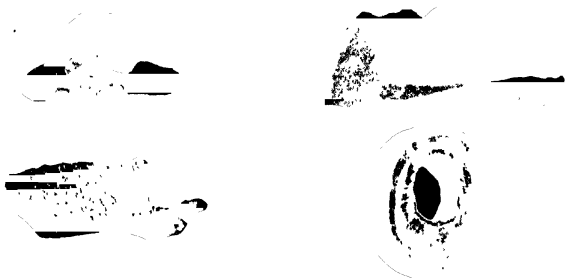
SCALE LOOSENED FROM PLATES OF BOILERS, ALSO BOILER TUBE
NEARLY FILLED WITH SCALE

Edw. C Schmidt, from a series of tests of locomotive tubes covered with different thicknesses of scale up to one-eighth in, draws the following conclusions

1. Scale varying in thickness up to ⅛ in. causes a heat loss varying from insignificant amounts up to as much as 10 or 12%.
2. The loss increases somewhat with the thickness of the scale.
3. The mechanical structure of the scale is of as much or more importance than the thickness in producing this loss.
4. Chemical composition, except insofar as it affects the structure of the scale, has no direct influence on its heat-transmitting qualities.

In confirmation of this, it is stated that 120 tests by the *Illinois Central Railroad* showed that the miles run per ton of coal were 11% greater during periods of one month after cleaning boilers than during the three months before cleaning. *E. W. Fiske* states that from tests made for three months previous to and three months after scale was removed from a boiler, it was found that the saving at the coal pile was 10% in favor of the clean heating surface

The loss from using unsoftened scale-forming water in boilers is represented principally by:

1. The extra coal consumed.
2. The cost of extra boilers to make up for the limitations on boiler capacity imposed by scale-forming water.
3. The cost of extra boilers in order to provide for standby in cleaning.
4. The cost of cleaning, retubing and repairing boilers.
5. The cost of firing up boilers put out of service for repairing and cleaning.
6. The depreciation on boilers, of which the life is greatly shortened by corrosion, pitting, cleaning, expansion and contraction strains and other evil effects of scale-forming feed water.
7. Cost of city water where a cheaper supply could be used were it not for scale-forming matter contained.
8. Cost of boiler compounds.
9. Damage to engines or turbines or limitation of efficiency thereof due to sludge in the steam or priming resulting from the use of unsoftened water.

Natural Impurities.—Suspended matter, as distinguished from dissolved solids, may include mud, silt or clay, vegetable matter, sewage and factory waste. It may cause an extremely troublesome scale, particularly if it contains oil, it may consolidate with the dissolved scale-forming solids, it may form heavy mud deposits in the boiler, and it may collect at the surface of the water and cause foaming and priming. It can be removed by filtration, by sufficiently prolonged sedimentation, or by coagulation. Most boiler waters which require chemical treatment contain the scale-forming calcium and magnesium salts in such quantity that, if lime and soda ash are added at a temperature of 205° F. or higher, the reactions are rapid and result in a flocculent precipitate, which in settling collects the original suspended matter and clarifies the water. This effect can be supplemented where necessary by filters. There are many cases in which mere heating of water causes coagulation of the suspended matters; in others coagulating chemicals can be used, followed by a second chemical to precipitate the coagulate.

The following are the principal scale-forming and corrosive salts found dissolved in water supplies, and the chemicals recommended for their removal.

Solids dissolved in water:	Precipitating reagents:
Calcium bicarbonate $Ca(HCO_3)_2$	Hydrated lime, $Ca(OH)_2$, or caustic soda $NaOH$
Calcium sulphate, $CaSO_4$	Soda ash (sodium carbonate), Na_2CO_3
Calcium nitrate, $Ca(NO_3)_2$	Soda ash
Magnesium bicarbonate $Mg(HCO_3)_2$	Hydrated lime or caustic soda
Magnesium sulphate, $MgSO_4$	Hydrated lime and soda ash, or caustic soda
Magnesium chloride, $MgCl_2$	" " "
Magnesium nitrate $Mg(NO_3)_2$	" " "
Iron salts	" " "
Sulphuric acid, H_2SO_4	" " "

Calcium is found in nearly all natural water supplies. Calcium oxide, CaO, known as quicklime, combines with water to form calcium hydroxide, or hydrate, $Ca(OH)_2$, known also as caustic or slaked lime, and soluble in water to form lime water, the mixture forming milk of lime or white-wash if there is an excess of the hydrate. Calcium oxide combines with carbon dioxide to form calcium monocarbonate, $CaCO_3$, which occurs in nature as calcite, marble or limestone. By itself it is only slightly soluble in pure water, but with the addition of another molecule of carbon dioxide and one of water it forms calcium bicarbonate, $Ca(HCO_3)_2$, which is highly soluble, and is the form in which calcium is taken up from carbonate rocks by rain water containing carbon dioxide in solution. The magnesium carbonates are similar in their properties to the corresponding calcium salts, with the exception that the monocarbonate of magnesium is quite soluble. The carbonate salts of lime and magnesia are often referred to as "temporary hardness," because they are precipitated to a considerable degree by heating the water, which drives off carbon dioxide from the bicarbonate, forming the monocarbonate, which, in the case of lime at least, is relatively insoluble.

Sulphate of lime, or calcium sulphate, occurs in nature with the addition of seven molecules of water as gypsum, or alabaster, which when heated dry gives up some of the water of crystallization and becomes a fine, white powder known as plaster of Paris. It is soluble in water,

to the extent of 138 4 grains per gal. at 60° F., and even at 300° F. is still soluble to the extent of 17 to 30 grains per gal. If allowed to concentrate in the boiler, the sulphate crystallizes out as a hard, porcelain-like scale, which is both very resistant to the passage of heat and difficult of removal, differing in this respect from the carbonate, which forms a soft, porous scale in the boiler. Magnesium sulphate is highly soluble, but, when calcium salts are also present in the boiler, it reacts with them, forming calcium sulphate, which is deposited as hard scale. Magnesium chloride breaks down, when heated to boiler temperature, probably forming magnesia and hydrochloric acid, thus producing corrosion.

Free sulphuric acid, found in mine water, is very corrosive; iron salts, while usually found in very small quantities, form a troublesome scale, especially in pipe lines. Some may be precipitated effectively by oxidation through aeration, but better results are obtained by the same chemical treatment used for the other impurities. Silica (silicon oxide), SiO_2, is also usually classed as a scale-forming solid, but is generally present in very small quantities, except in well waters containing free sodium carbonate, and needs no particular attention.

The salts of sodium and potassium are highly soluble and do not cause scale or corrosion, but if allowed to concentrate within the boiler will cause foaming and priming. They cannot be removed by any practical chemical treatment, but must be kept within the necessary limits by periodically blowing down the boiler. They include·

Sodium carbonate, Na_2CO_3	Potassium carbonate, K_2CO_3
Sodium sulphate, Na_2SO_4	Potassium sulphate, K_2SO_4
Sodium chloride, $NaCl$	Potassium chloride, KCl
Sodium nitrate, $NaNO_3$	Potassium nitrate, KNO_3

Sodium occurs in large quantities in some water supplies, particularly near the sea, as the chloride (common salt), and is found in other localities as the carbonate.

All natural waters also contain dissolved gases, air and CO_2. When the water is heated to boiling point in an open heater, their solubility is so reduced that removal is practically complete. Hydrogen sulphide, H_2S, which may be detected by its odor, is also found in some ground water or water from artesian wells. It is also removed by heating, and the corrosive action of any traces remaining will be neutralized by the softening chemicals added to precipitate the scale-forming solids. Many waters contain substances ordinarily termed volatile and organic matter, such as sewage, factory wastes and vegetable matter leached out in flowing through swamps or woods, which are difficult to remove by any practicable means, although heating to 205° F. and treatment with softening chemicals will effect coagulation or precipitation with the scale-forming impurities, and the behavior in the boiler of the neutralized matter remaining in solution will be similar to that of other soluble salts.

Mechanism of Scale Formation.—The most common scale found in boilers is calcium sulphate, the solubility of which decreases with increase in temperature, the solubility also depending in part upon the combined water, as shown in Fig. 1, due to *R. E. Hall.* Upon concentration to the saturation point the calcium sulphate crystallizes directly on the tubes and acts as a binder for other materials that may be in suspension, such as organic matter, calcium carbonate, magnesium hydrate, etc., playing the same part in scale formation that cement does in concrete. Generally speaking, with increasing amounts of calcium sulphate the scale becomes harder.
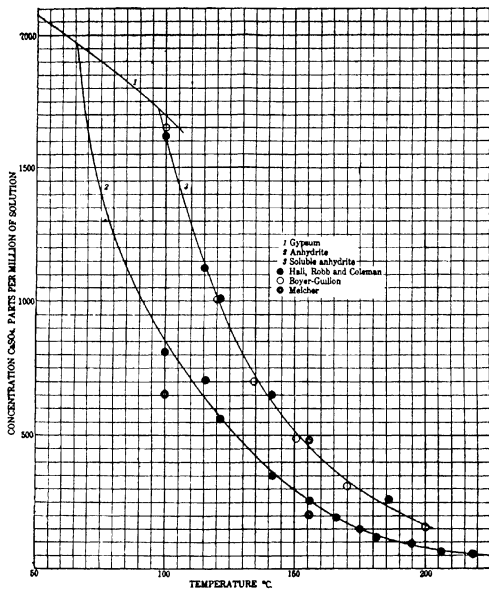
FIG 1.   SOLUBILITY OF CALCIUM SULPHATE

FIG. 2.   SHOWING INCLUSION OF MAGNESIUM SILICATE AND CALCIUM CARBONATE BY A FRAMEWORK OF CALCIUM SULPHATE CRYSTALS.

FIG. 3.   THIN SECTION OF CALCIUM SULPHATE SCALE.   *Carnegie Inst Bull.*
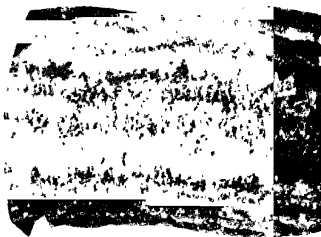
FIG. 4.   TYPICAL MAGNESIUM SILICATE SCALE WITH INCLUSION OF
          CALCIUM CARBONATE CRYSTALS. *Carnegie Inst Bull*

Hard scale may contain as little as 10% of calcium sulphate, although some
scales show 80%, 90% or more calcium sulphate   Ordinarily calcium
sulphate can be distinguished in a cross-section of the scale as needle-like
crystals, as shown in Fig. 2, due to *Hall*.

Calcium carbonate, even in the presence of considerable amounts of
soda, will also form a hard scale in certain types of boilers if driven at
high ratings, for which reason it is advantageous to remove the greater part
of the hardness outside of the boiler. *Hall* states that the hard adherent
scales are formed by crystallization from the saturated boiler water directly
on the surfaces where found when the boiler is opened, and that in this mode
of formation the crystals responsible for the growth of the scale have never
been present as individual particles free to follow the flow of the boiler
water and to be deposited in haphazard fashion on the surfaces. In a calcium
sulphate scale, for instance, the major dimension of the crystals is normal
to the evaporating surfaces, and as a rule crystal growth takes place with
the formation of elongate crystals growing radially   Growth along any
individual crystal axis proceeds for weeks or months   Fig. 3 is a thin
section of this type of scale photographed at low magnification by transmitted
light.

He states that three substances deposit from the boiler water in this
manner—namely, calcium sulphate, calcium silicate and magnesium silicate.
Calcium hydroxide belongs in this class, but its presence in scales in appreci-
able quantities is unusual. The presence of calcium carbonate, and presum-
ably of magnesium hydroxide also, in adherent scales, is due to the incor-
poration of loose crystals thereof in a matrix of one or more of the three
substances mentioned. Thus in Fig. 2, the framework of the scale is evi-
dently the large interlocking crystals of calcium sulphate, while in the
interstices are found magnesium silicate and calcium carbonate. In Fig. 4,
the framework is composed of hydrous magnesium silicate.

In Fig. 5, the relative proportions in which these ingredients may be
present in scales and sludges is shown by a triangular diagram. To interpret
the analysis of a scale for this purpose, the iron and aluminum oxides are
disregarded, as they are usually small in amount, and the silica, magnesia,
water (net ignition loss in the analysis), and any lime not required by SO_3
and CO_2 collectively is termed silicate.   No great error is entailed in the
latter, as hydrated magnesium orthosilicate is always the predominant silicate
present when there is much combined water in the scale; and when calcium
metasilicate is present in predominant quantity the amount of combined
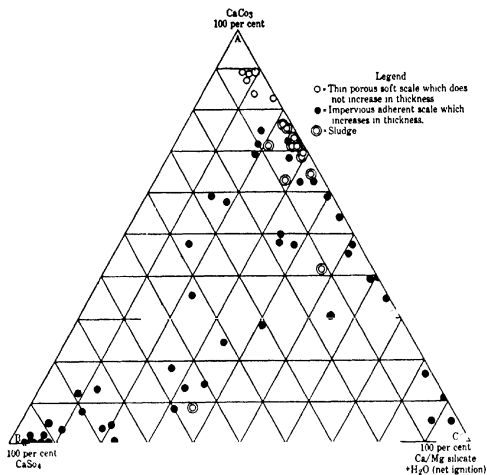
FIG. 5. RELATION OF CALCIUM CARBONATE, CALCIUM SULPHATE, AND CALCIUM AND MAGNESIUM SILICATE IN ADHERENT SCALES. *Carnegie Inst. Bull.*

water is small. Because the oxides of iron and aluminum are disregarded, the values for calcium carbonate, calcium sulphate, and the collective silicate must be proportionally increased slightly, so that they total 100%. The solid circles in Fig. 5 represent the adherent scales, which are characterized by their tendency to grow in thickness and to be impervious to water. Those which lie near the *B* and *C* apexes of the triangle are exceedingly hard. Those composed of carbonate and sulphate, with low silicate content, are soft, but grow in thickness; those which lie along the line *AC* are characterized in general by less thickness and is usual in the sulphate carbonate scales, and by a hardness which decreases from *C* to *A*. The single open circles near *AC* represent the composition of the thin, porous scale characterized by not increasing in thickness, which results when the boiler-water equilibria are controlled by the use of sodium carbonate. The double open circles represent composition of sludges. The two sludges near the *BC* line are special cases resulting from extreme high-sulphate concentration in the feed water; the others are typically the result of the use of a high-carbonate, low-sulphate water without treatment or of any of the common natural waters with treatment.

Rapid Examination of Water.—The so-called "rapid methods of water analysis" do not give reliable results even when used by experienced chemists. A soap test will give the total hardness or soap-consuming power of a water, but will not give the sodium salts, as the soap reacts only with the calcium and magnesium salts. The soap test may show one water to be of much lower hardness than another, while complete analyses may

show the water of lower hardness to be very high in sodium salts and therefore inferior for industrial uses. It is recommended that when the mineral contents are desired a complete analysis (see p 728) be made by a reliable chemist, showing: (1) suspended matter, (2) free CO_2, (3) total dissolved solids by evaporation, (4) chlorides, (5) bicarbonates and carbonates, if present, (6) sulphates, (7) nitrates, (8) silica, (9) iron oxide and alumina, with a separate determination of iron if the total of these two is above one grain per gallon, (10) calcium and (11) magnesium. This ionic analysis should be combined according to one of the methods described on p. 730. The organic matter is obtained by subtracting the solids by combination from the total dissolved solids by evaporation. When information is desired as to changes which may occur from time to time in a particular water supply, an initial complete analysis can be supplemented by frequent soap and alkalinity tests, which will reflect the changes fairly accurately. The total mineral content increases in seasons of drought, and decreases in wet seasons, and as the change in hardness-producing salts is in general proportional to that in the sodium or non-hardness-producing salts, the soap test gives a useful gage.

The **soap test** is based on the fact that a lather will not be obtained upon the addition of soap to an agitated sample of water until all the calcium and magnesium salts have reacted with the sodium or potassium soap to form insoluble calcium and magnesium soaps. After sufficient soap has been added to combine with the calcium and magnesium a slight excess will produce a lather. A soap test is therefore a close determination of the total calcium and magnesium in a water, not of either one separately, but is usually reported in terms of so many grains of calcium carbonate per gallon. The report of hardness-producing salts in a complete analysis can also be reduced to terms of calcium carbonate by multiplying the content of the several salts by the following factors:

Calcium carbonate	1.000	Magnesium carbonate	1.186
Calcium sulphate	.735	Magnesium sulphate	.833
Calcium chloride	.900	Magnesium chloride	1.050
Calcium nitrate	.610	Magnesium nitrate	.675

The apparatus required for a soap test is as follows:

Standard soap solution with curve showing hardness, as on page 725
1 burette, about 25 ml. capacity, with glass cock or burette attachment.
1 stand
1 burette clamp.
1 burette cap.
1 50 ml. graduated cylinder.
1 bottle, about 250 ml. capacity

A soap solution frequently used for tests is the standard of the *American Public Health Association*, in the preparation of which they recommend the use of castile soap However, changes in the moisture content of soap often make it difficult to duplicate a solution without spending considerable time, and such solutions may also solidify at temperatures not much below ordinary room temperature. The following instructions cover the making of an olive oil and *KOH* solution equivalent in strength to the *A P. H A.* standard· To make one liter of solution take one gram of potassium hydroxide and dissolve it in a small quantity of distilled water. When the solution is complete add 100 ml of wood alcohol Weigh in a tared flask or beaker of about 400 ml. capacity 5 9 grams of olive oil Pour the potassium hydroxide solution into the vessel containing the olive oil heat and shake frequently until the oil is saponified. Cool the soap formed and add enough wood alcohol to make 1 liter, filter the solution if necessary Have a sample of water, taken preferably during a dry period. analyzed by a chemist If the total calcium and magnesium salts, converted to grains of calcium carbonate per gallon, are less than 5.9, the solution prepared as above can be used, and is standardized as follows:

   Take 50 ml. of the water analyzed and pour it into a bottle of about 250 ml

capacity. From a burette add soap solution 1 ml at a time, shaking the bottle after the addition of each ml, until a lather starts to form. Now add the soap solution 0.1 ml. at a time until a lather is formed which lasts for five minutes when the bottle is placed on its side. Some waters show a false lather which disappears upon the addition of more soap. It is always advisable to check the amount of soap required to give the permanent lather by adding more soap to the sample, and if the lather disappears continue adding soap until a permanent lather is formed. If the lather becomes heavier than the original amount of soap was correct. The amount of soap used is recorded as equivalent to the hardness of the water in terms of calcium carbonate. Now prepare a series of samples of decreasing hardness by taking 40, 30, 20 and 10-ml. samples of the water and diluting to 50 ml with distilled water. Determine the amount of soap solution required to give a lather with each sample, and plot a curve showing the hardness corresponding to different amounts of soap solution, from 0 to 7.9 ml. A soap solution should be kept in a dark bottle, protected from the light and tightly stoppered to prevent evaporation of the alcohol.

To make a soap test, take 50 ml of the water to be tested and pour it into a bottle of about 250 ml capacity. Add soap solution from a burette, taking small quantities as the lather starts to form, being sure to time the process, so as to determine when the first permanent lather is formed, lasting for five minutes. From the standardization curve for the soap solution the total hardness corresponding to the amount of soap used may be obtained. If the solution has been accurately standardized and the test properly made the results obtained will check an analysis within $\frac{1}{10}$ of a grain per gallon.

Not more than 7.9 ml. of the standard solution above described should be used to a 50 ml sample of water. This corresponds to a hardness of 5.9 grains per gallon. If a sample of water requires more than 7.9 ml of solution, the A P H A advises taking a smaller sample, diluted to 50 ml. with boiled distilled water, making the necessary correction in reporting the hardness of the water tested. This dilution of course reduces the accuracy of the test, and if waters averaging high in hardness are to be tested it is desirable to make a solution of double or triple the quantities of potassium hydroxide and olive oil mentioned in the above, standardizing the solution by the same process.

Alkalinity and Salt Tests.—For illustration and list of apparatus see page 754.•

The alkalinity test, besides determining the alkalinity of the feed water or boiler water, also distinguishes the various chemicals that cause this alkalinity. The salt test determines the amount of sodium chloride, or, perhaps, of chlorides of calcium and magnesium. In what follows, all the tests are in terms of sodium chloride, as it makes no difference whether the chloride is in the form of sodium chloride, magnesium or calcium chloride. Tests for alkalinity are made in two steps, the determination of *Ph* alkalinity (using phenolphthalein as the indicator), and the determination of the *M.O.* alkalinity (methyl orange indicator).

The procedure is as follows:

1. Measure out 100 ml. of water to be tested.
2. Pour into porcelain dish and add one drop of phenolphthalein indicator. This will turn the water red if it contains sodium carbonate (soda ash) or caustic soda or lime. If the indicator fails to turn red it is an indication that none of the above chemicals is in solution.
3. Fill up burette to zero mark with twentieth normal sulphuric acid.
4. Gradually add (titrate) the acid to the water until the red color starts to fade out. Continue adding until the faint pink color remaining entirely disappears. Take the reading and note this as the Ph. alkalinity.
5. To the same sample add two drops of methyl orange indicator and continue the titration with acid without filling the burette to the zero mark. In case the "Ph" reading was zero this test will start from zero. The indicator will change the water to a yellow color in the presence of any alkali.
6. Add acid until the yellow color just changes to an orange. This reading is the methyl orange or "M.O." alkalinity.
7. On the sample of water used for the "Ph" and "M.O." tests add 4 drops of potassium chromate indicator. This will turn the water yellow.
8. Fill the second burette to the zero mark with standard silver nitrate.
9. Add (titrate) silver nitrate slowly from the burette. Approaching the end point, a red color will appear and then disappear with each addition of silver nitrate. Continue the titration until this red color just stays permanent, giving the sample

a faint brownish red tinge. This is the end point and the ml of silver nitrate used represents grains per gallon of salt when the original water sample was 100 ml.

The Ph or $M.O.$ alkalinity, multiplied by 1 5, gives the corresponding alkalinity in grains per gallon expressed as sodium carbonate. In making titrations on a concentrated sample such as boiler water, a quick determination of the end point can be obtained by adding four drops of titrating solution as the test nears completion. This will ordinarily carry the test beyond the end point, making the change in color more distinct. To make a correction for this overrunning, 0.1 ml. is then subtracted from the reading. Four drops corresponds to 0 2 ml., so that a plus or minus error of 0.1% may be introduced under certain conditions, but this is within the limit of error for such determinations where the water is fairly high in alkalinity and salt, as in a concentrated boiler water. For waters low in minerals, such as raw or treated water, a more accurate method is to add the solution a drop at a time.
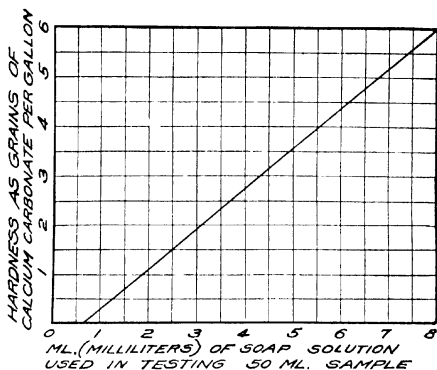
STANDARDIZATION CURVE FOR SOAP SOLUTION—*Am. Pub Health Assn.*

TOTAL HARDNESS IN PARTS PER MILLION OF $CaCO_3$ FOR EACH TENTH OF A MILLIMETER OF SOAP SOLUTION WHEN 50 ML. OF THE SAMPLE IS TITRATED.—From *A. P. H. A.* book "Standard Methods of Water Analysis."

Milliliters of Soap Solution	0.0	0.1	0.2	0 3	0 4	0.5	0 6	0.7	0.8	0.9
0.0	—	—	—	—	—	—	—	0.0	1.6	3.2
1.0	4.8	6.3	7.9	9.5	11.1	12.7	14.3	15.6	16.9	18.2
2.0	19.5	20.8	22.1	23.4	24.7	26.0	27.3	28.6	29.9	31.2
3.0	32.5	33.8	35.1	36.4	37.7	39.4	40.3	41.6	42.9	44.3
4.0	45.7	47.1	48.6	50.0	51.4	52.9	54.3	55.7	57.1	58.6
5.0	60.0	61.4	62.9	64.3	65.7	67.1	68.6	70.0	71.4	72.9
6.0	74 3	75.7	77.1	78 6	80.0	81.4	82.9	84.3	85.7	87.1
7.0	88.6	90.0	91.4	92.9	94.3	95.7	97.1	98.6	100.0	101.5

If the soap and acid solutions are both standardized in the manner described, in terms of calcium carbonate, the reports as to hardness, H, and alkalinity, A, can be interpreted as follows:

If $H = A$	Temporary hardness only
If H is not zero, $A = O$	Permanent hardness only
If A is not zero, $H = O$	Sodium alkalinity
If H exceeds A	Temporary and permanent hardness
If A exceeds H	Temporary hardness and sodium alkalinity

"Temporary hardness" is caused by bicarbonates of calcium and magnesium (generally reported in terms of carbonates), and is largely removed by prolonged heating, which causes the liberation of the half-bound CO_2 and the precipitation of the carbonates. Permanent hardness is caused by the sulphates, chlorides and nitrates of calcium and magnesium, which do not precipitate upon heating. Sodium alkalinity is due to sodium bicarbonate, generally reported in terms of sodium carbonate.

Practical Interpretation of Water Analysis.—*C. E. Joos* makes the following suggestions concerning certain uses to be made of alkalinity and salt tests. The salt content of water means little in itself, but salt readings from several parts of the plant in which it is used may be quite useful. In a plant which is using an unknown quantity of condensate, but where the amount of water evaporated is known, if the feed water contains two grains of salt per gallon and the combination of raw water and condensate shows a salt content of one grain, then the mixture contains 50% of raw water and 50% of condensate, provided that the condensate is not contaminated as a result of priming or condenser leakage. A similar interpretation can also be made for a mixture of treated water and condensate where a softening system is used.

In the absence of a meter, the evaporation can also be approximated by determining the rate of concentration of sodium chloride in the boiler. It is only necessary to fill the boiler initially with fresh water up to a predetermined level, and run for any desired length of time, as for 24 hr., at the end of which time the water level is brought up to the original level and the concentration of salt in the boiler water determind. Knowing the amount of salt in the feed water and the concentration of salt in the boiler water, the number of boiler volumes of water that have been evaporated can be computed by dividing the salt concentration of the boiler water by the salt concentration of the feed water. Knowing the volume of the boiler, the exact amount of water can be calculated. The boiler should not be blown down during the interval of testing. Such an approximation does not take into account the quality of the steam. All moisture leaving the boiler will carry with it a certain amount of solids depending upon the concentration, which makes it necessary to apply a correction to the actual salt concentration. The following data are assumed for the purpose of an example:

Salt in feed water	1.0 gr. per gal.
Salt in boiler water after test	30.0 gr. per gal.
Average moisture in steam	1%
Volume of boiler	3000 gal.

To apply the correction for moisture; the average concentration of salt in the boiler is $(30 + 1)/2 = 15.5$ gr. If all the steam were condensed, each gallon would contain 1% of 15.5 gr., or 0.155 gr. average. This means that every gallon of water leaving the boiler as steam would carry with it

0.155 gr. of salt, and since the salt content of the water entering the boiler is 1 gr. per gal., the salt remaining in the boiler would be $1.0 - 0.155 = 0.845$ gr. for every gallon fed. Therefore, the amount of water entering the boiler under the conditions above described would be $3000 \times 30/0.845 = 106,500$ gal. 99% of this would be steam and 1% moisture.

In order to determine total solid content of a boiler water, it is only necessary to make periodic evaporation tests of the filtered boiler water, determining the relationship between the total solids and the salt, and apply this relationship to the daily test for salt. As an example, suppose the total solid content of the filtered boiler concentrate is 250 gr. per gal. and the sodium chloride or salt concentration is 25 gr. per gal., then the factor, or the total solids per gram of salt, would be 10, and this factor multiplied by any other sodium chloride reading would give the corresponding total solid content of this sample.

In making titration tests on boiler water, usually the water in every boiler is tested in sequence. A systematic record of these tests will disclose certain operating conditions. For example, if two or more boilers are fired in exactly the same manner and deliver the same amount of steam, the concentrations should be practically identical. If one boiler shows a concentration consistently lower than the others, the low concentration may be due to a leaky blowoff valve, which can easily be checked up by noting by touch the temperature of the blowoff pipe beyond the blowoff valves, or water may not have been evaporated at the same rate per pound of coal as in the other units, in which case look for broken boiler baffles, and check by noting the flue gas temperature as compared to the other units.

The efficiency of chemical treatment of the feed water can be determined if the feed water and the boiler water be tested both for salt and for sulphates and the sulphates be calculated to a common basis, as to sodium sulphate, and the ratio of sodium sulphate to salt determined.

Referring to data in the table below, if in the feed water the amount of sulphates calculated in terms of sodium sulphate per gram of salt is 2 5, we would expect the same ratio to exist in the boiler if no scale formation or disintegration was taking place. This is indicated under Analysis No. 1. Such a condition indicates that the water going to the boiler is softened, that the boiler originally was clean, no scale was carried down and no new scale was formed. Analysis No. 2 of the concentrated boiler water indicates a lower quantity of sulphate per gram of salt than the feed water. Such a ratio means that the sulphate radical is going out of solution in the boiler water, with the formation of calcium sulphate scale.

FEED WATER		No 1	No 2	No. 3
Sodium sulphate	5 0	90 0	90 0	90.0
Sodium chloride	2.0	36 0	70 0	16.0
$Na_2SO_4/NaCl$	2 5	2 5	1.3	5.6

In Analysis No. 3, however, the quantity of sulphate per grain of salt in the boiler water is much greater than 2 5, showing that the sulphates have come into solution after the feed water entered the boiler. This means that the chemical treatment is disintegrating the old scale and converting the calcium sulphate scale to the soluble form of sodium sulphate. The method of interpretation deals only with calcium sulphate scale and is no indication as to whether or not the calcium silicate scale is being formed or removed. This can be determined if similar analyses are made for silica instead of sulphate.

After the installation of a softening system, it is desirable to determine the extent of the removal of calcium and magnesium salts and the amount of calcium and magnesium carbonates remaining in the treated water. Ordinarily this is determined by a careful analysis by an experienced chemist. For approximate results, this is not necessary. Assume the following average of all daily readings taken from reports of operation on a hot process water softener, the figures being reported in grains per gallon:

	Ph.	M.O.	Salt
Feed water	1.4	3.0	2.5
Boiler water		30.0	37.5

Salt in boiler water divided by salt in feed water = concentrations, hence 37.5/2.5 = 15 concentrations.

The alkalinity of the boiler water represents the alkalinity due to soda (soda ash and caustic soda) and small quantities of calcium and magnesium carbonates, which may be neglected. The alkalinity (M.O.) of the treated water, however, is the alkalinity due to the carbonates of sodium, calcium and magnesium, in which case both the calcium and magnesium may make up as much as 50% of the alkalinity. Knowing the number of times that the feed water has been concentrated, the amount of soda originally in the water can be calculated Thus, in the above, the boiler water contains 30 gr. of alkaline sodium salts, which is the result of 15 concentrations. Therefore, by dividing the boiler alkalinity by the concentrations, the quotient will be the alkaline sodas present in the treated water, or 2 grains. Now, our treated water titration shows the presence of 3.0 gr. of alkalinity, or a difference of one grain, which represents the combined quantity of calcium and magnesium carbonates in solution in the treated water.

Complete Laboratory Analysis.—While the abbreviated tests, such as soap tests, alkalinity and soap tests, etc , give valuable indications of the character of water, they are at best not accurate measures, and where reliable information is needed, as for instance in the selection of a water-softening system, a complete analysis should be made by a qualified chemist. The method followed in the Cochrane laboratory, and given below, has been found reliable. The proper interpretation of these analyses depends largely upon the method of combining the individual metals and radicals determined by the complete analysis.

Suspended Matter—Take 500 ml. (milliliters or c.c.) sample; filter through a weighed Gooch; dry and weigh. If water contains large quantities of suspended matter, a smaller sample may be used.

Total Solids—Evaporate entire filtrate portion of filtered sample, such as 100 ml., in weighed platinum dish. Dry and weigh.

Organic Matter—The organic matter is calculated as the difference between the total solids determined by evaporation and the mineral solids as determined by analysis.

Silica—Evaporate a measured portion of the filtered water and to the residue add a few ml. of hot distilled water and a little HCl. Evaporate to dryness and bake in oven for one hour at 300° F. Add a few ml. hot distilled water together with a few drops of HCl and filter. Ignite precipitate in weighed platinum dish. Cool in desiccator and weigh.

Iron and Alumina—Heat a desirable measured portion of filtrate to boiling. Add NH_4OH until alkaline. Boil, filter, wash, dry and ignite in weighed porcelain crucible. Cool and weigh.

Calcium Oxide—Evaporate filtrate from iron and alumina determinations to 100 ml. Boil, add hot $(NH_4)_2 C_2O_4$ solution, still stirring. Allow to settle, filter, wash and ignite precipitate in weighed platinum crucible. Cool and weigh as CaO, calculate and report in terms of Ca

Alternative Titration Method for Ca—After precipitation with ammonium oxalate, wash the precipitate on the filters until free from ammonium oxalate. Place the filter containing the calcium oxalate in a beaker; add about 75 ml. of water and 10 ml. of 25% concentrated sulphuric acid Titrate the liberated oxalic acid with $N/20$ potassium permanganate solution. On the basis of using a 500 ml sample, multiply the number of ml. of permanganate solution required by 2 in order to get calcium in parts per million. If the permanganate solution is not exactly $N/20$, correct by means of the normality factor.

Magnesium—Evaporate filtrate from calcium determination to about 75 ml. Acidify with HCl and add 15 ml. of $NaNH_4HPO_4$, and delute NH_4OH with constant stirring (being careful to keep rod away from beaker walls) until ammoniacal   Allow to stand over night, filter, wash with dilute ammonia and weigh as $Mg_2P_2O_7 \times 0.215 = Mg$

Alternative Titration Method for Determination of Magnesium.—The filtrate from the calcium determination with all of the wash water is made just acid with hydrochloric acid, placed on the sand bath and evaporated until the salts in solution begin to crystallize out. Add 10 ml. of the sodium ammonium acid phosphate solution, which should be ample excess to precipitate all the magnesium. If a precipitate forms, dissolve by adding a small amount of hydrochloric acid. Add slowly ammonium hydroxide until distinctly alkaline. While adding the ammonium hydroxide stir the solution vigorously with a rubber tip stirring rod. Allow the solution to stand twelve hours in a cool place before filtering. Filter, catching the filtrate in a clean beaker, and if any precipitate passes through, filter again. It is not necessary to transfer all the magnesium to the filter paper, but it should be thoroughly washed four or five times (about 8 to 10 ml added each time) with an ammonium hydroxide solution (5 ml. diluted with distilled water) to 250 ml. Wash the precipitate on the filter paper back into the beaker with 50 ml. of distilled water and dissolve with 5 ml. of dilute acetic acid (5 ml. diluted to 100 ml. with distilled water) ; heat if necessary to dissolve the precipitate.

Cool the solution and add standard uranium acetate solution, with constant stirring until a brown color is produced, when one drop is added to a drop of the potassium ferro-cyanide indicator on a porcelain plate. The amount of uranium acetate to add before the color reaction will be obtained can be fairly closely estimated, after a little experience, by noting the volume of precipitate. Now heat to the boiling point and again add a drop to the indicator and add uranium acetate solution slowly until the end point is reached. The solution must be boiling at the final end point.

The number of ml. of uranium acetate solution added to the sample, multiplied by the magnesium equivalent of one ml., will give the amount of magnesium contained in the sample. This result multiplied by two will give the parts per million of magnesium.

Chlorides—A 100 ml. sample of filtered water should be titrated with a known strength silver nitrate solution, using potassium chromate as an indicator. The silver nitrate should be added until a red color just appears. If a water is to be tested for chlorides having alkalinity due to hydrates, a

drop of phenolphthalein should be added and diluted sulphuric acid added from a burette until the red color disappears, then continue with a chlorine determination with silver nitrate as indicated above.

Sulphur Trioxide, SO_3—Take 250 ml. filtered water. Boil down to smaller volume. Acidify with hydrochloric acid, add boiling $BaCl_2$ solution slowly. Allow to settle, filter, ignite and weigh as $BaSO_4$.

Weight of $BaSO_4 \times 0.343 =$ weight SO_3

Report all results in terms of parts per million and follow the procedure as given below in making the necessary combinations

Combining Analyses.—*J. D. Yoder* discusses the calculation of hypothetical combinations from "uncombined" analyses, as in columns A-1 and B-1 for two waters investigated. The uncombined analyses, showing metals and acid radicals, are not adapted for boiler feed study, as they do not show whether magnesium chloride is present or if equivalent amounts of calcium carbonate are present to combine with all the magnesium sulphate or whether the carbonates are present in equivalent amounts to combine with the calcium and magnesium. He recommends the method of combining used by the *Cochrane Corporation* and shown in columns A-2 and B-2, determined as follows·

When the HCO_3, CO_3 and SO_4 radicals equal or exceed the calcium and magnesium requirements, the solids are combined in the following order
1. Change the bicarbonate (HCO_3) to its equivalent monocarbonate (CO_3) radical.
2. Magnesium (Mg) with carbonate (CO_3)
3. Remaining carbonate (CO_3) with calcium (Ca).
4. Remaining carbonate (CO_3) with sodium (Na).
5. If remaining carbonate (CO_3) is insufficient for calcium, combine the remaining calcium with sulphate (SO_4).
6. Remaining sulphate (SO_4) with sodium (Na).
7. Chloride (Cl) with sodium (Na).
8. Nitrate (NO_3) with sodium (Na).

When the bicarbonate (HCO_3), monocarbonate (CO_3), and sulphate (SO_4) radicals are less than the calcium and magnesium radicals, combine the solids in the following order.
1. Change the bicarbonate (HCO_3) to its equivalent monocarbonate (CO_3) radical.
2. Calcium (Ca) with sulphate (SO_4).
3. Remaining sulphate (SO_4) with magnesium (Mg).
4. Remaining sulphate (SO_4) with sodium (Na).
5. If calcium is in excess of sulphate (SO_4), combine calcium (Ca) remaining after No. 2, with carbonate (CO_3).
6. Remaining carbonate (CO_3) with magnesium (Mg).
7. Remaining magnesium (Mg) with chloride (Cl).
8. Remaining chloride with sodium (Na).
9. Nitrate (NO_3) with sodium (Na).

Column A-2 clearly shows that the calcium and magnesium in water *A* are in excess of the carbonates and because of the excess calcium present as a sulphate this water would form a considerable amount of hard scale in the boiler. It further shows that the water does not contain magnesium in excess of the carbonates or that any magnesium might be present as a sulphate or chloride to cause corrosion. The amounts of sodium sulphate and chloride are clearly given. B-2 shows that the calcium and magnesium in water *B* are present in excess of their equivalent carbonate radicals, leaving calcium sulphate in solution to cause a hard scale formation. The analysis further shows the calcium and magnesium to be in excess of the carbonates and sulphates, leaving some magnesium chloride in solution, which would be corrosive except for the relatively small amount of magnesium chloride present in this case as compared with the calcium and magnesium carbonates. Method 2 shows the calcium and magnesium com-

bined with the acid radicals with which they would be deposited as scale in the boilers, and therefore reveals the character of both water supplies for boiler feed purposes.

He also suggests the method shown in columns 3, for which the calcium and magnesium are combined with the acid radicals in the same order as column 2, the only difference being that the calcium and magnesium are reported in their bicarbonate form as they exist in raw water, instead of in their monocarbonate form as they would be deposited in the boiler. Reporting calcium and magnesium bicarbonates has not been a very popular method, probably for the reason that calcium and magnesium bicarbonates have never been isolated or cannot be separated from the water. The calcium and magnesium bicarbonates are of necessity changed to their respective monocarbonates, in which form they are deposited in the boilers. Nevertheless, it is evident that much might be said in favor of this method of reporting analyses. If the calcium and magnesium are present in their bicarbonate form when delivered to the boiler, they will crystallize out as a comparatively soft scale in the boiler, whereas calcium and magnesium monocarbonate, as present in water properly treated by the lime and soda process, will be deposited in the boiler as mud or suspended matter. Furthermore, it is evident that if calcium and magnesium bicarbonates are delivered to the boiler, CO_2 will be liberated during the process of precipitating calcium and magnesium carbonates. If waters containing calcium and magnesium bicarbonates are treated by zeolite softeners, corresponding amounts of sodium bicarbonate will be delivered to the boilers, which will be dissociated into carbon dioxide, sodium carbonate and sodium hydrate or caustic soda. It is for this reason that high carbonate waters treated by zeolite softeners will result in feeding boilers with water comparatively high in half bound CO_2. Inasmuch as the same order was followed for combining these analyses as for column 2, the same remarks made regarding the sulphates and chlorides of calcium and magnesium as given for column 2 apply.

METHODS OF REPORTING WATER ANALYSIS
(All in parts per million)

Sample No.	A	A	A	B	B	B
Method No.	1	2	3	1	2	3
Bicarbonate	250 1	.	..	255	.	..
Carbon Dioxide	16	16	16	11	11	11
Calcium	62	.	...	76 22	.	...
Calcium Carbonate	...	78	...	...	132	..
Calcium Bicarbonate	...	..	127	..	...	214
Calcium Chloride	...	...	..	. .	..	..
Calcium Sulphate	..	105	105	.	79	79
Chloride	11	...	...	43.5	...	...
Iron Oxide and Alumina	3 6	4	4	Trace	Trace	Trace
Magnesium	31	.	.	20 6	...	...
Magnesium Bicarbonate	...	.	186	..	...	113
Magnesium Carbonate	..	107	...	..	65	...
Magnesium Chloride	...	..	..	..	7	7
Magnesium Sulphate	...	...	..	...	...	...
Silica	18	18	18	5 2	5	5
Sodium	37.7	..	..	24 8	...	...
Sodium Chloride	...	18	18	..	63	63
Sodium Sulphate	..	94	94	...	...	...
Sulphate	138	...	...	56	...	...
Suspended Matter	238	238	238	45	45	45
Total Solids by Evaporation	480	480	480	393	393	393
Volatile and Organic	56	56	56	42	42	42

CONVERSION FACTORS

DEGREES OF HARDNESS

1 American Degree of Hardness = 1 Grain $CaCO_3$ per U. S. Gallon
1 English Degree of Hardness = 1 Grain $CaCO_3$ per Imperial Gallon
1 French Degree of Hardness = 1 part $CaCO_3$ per 100 000
     = 583 grain $CaCO_3$ per U. S. Gallon
1 German Degree of Hardness = 1 part CaO per 100 000
     = 583 grain CaO per U. S. Gallon

1 Grain per U. S. Gallon = 17 1526 parts per million
1 part per million = 0583 grain per U. S. Gallon
1 part per 100 000 = 583 grain per U. S. Gallon

MASS AND VOLUME EQUIVALENTS

	Pound	Ounce	Grain	Gram	U. S. Gal. at 62° F	Imp Gal. at 62° F	Liter at 62° F	Cu in. at 62° F	Cu ft. at 62° F
Pound (av.)		16 0	7000.	453 5924	0 11996	0 10	0 45410	27 715	0 01603
Ounce (av.)	0 625		437.5	28 35	0 0007497	0 00625	0 2838	1 732	0 00104
Grain	0 000143	0 002285		0 0648	0 0000170	0 00001428	0 00006487	0 09396	0 00000229
Gram	0 002204	0 035274	15.4322		0 0002641	0 0002204	0 001	0 06102	0 0000353
U. S. Gal, Water at 62° F	8 3356	133 3696	58349 2	3780 965		0 837318	3 78543	231 0	1 13368
Imperial Gal at 62° F	10 00	160.	70000	4535 924	1 19967		4 5413	277 418	0 16037
Liter water at 62° F	2.2021	35.234	15414 882	998 878	0 26417	0 2202		61 0234	0 035315
Cu in. water at 62° F	0 03608	0 57736	252 585	16 3679	0 0041329	0 003608	0 016387		0 0005787
Cu ft. water at 62° F	62 355	997 68	436 485	28283 764	7 4805	6 2355	28 31708	1728 0	

Meaning of Hardness of Water in Terms of Calcium Carbonate.—

The hardness of natural waters is due to dissolved salts of calcium and magnesium. Whether the water contains calcium carbonate, calcium sulphate, calcium chloride or calcium nitrate, the effect is just the same in causing hardness. This is also true for the several salts of magnesium.

When the hardness of water is measured by the amount of soap required to form a lather by shaking, the chemical reactions between the calcium and magnesium salts and soap (sodium oleate) are represented by the following equations

$$Ca(HCO_3)_2 + 2\ NaC_{15}H_{33}O_2 = Ca(C_{15}H_{33}O_2)_2 + 2\ NaHCO_3$$
$$CaSO_4 + 2\ NaC_{15}H_{33}O_2 = Ca(C_{18}H_{33}O_2)_2 + Na_2SO_4$$
$$CaCl_2 + 2\ NaC_{15}H_{33}O_2 = Ca(C_{18}H_{33}O_2)_2 + 2\ NaCl$$
$$Ca(NO_3)_2 + 2\ NaC_{15}H_{33}O_2 = Ca(C_{18}H_{33}O_2)_2 + 2\ NaNO_3$$
$$Mg(HCO_3)_2 + 2\ NaC_{18}H_{33}O_2 = Mg(C_{18}H_{33}O_2)_2 + 2\ NaHCO_3$$
$$MgSO_4 + 2\ NaC_{15}H_{33}O_2 = Mg(C_{18}H_{33}O_2)_2 + 2\ Na_2SO_4$$
$$MgCl_2 + 2\ NaC_{15}H_{33}O_2 = Mg(C_{18}H_{33}O_2)_2 + 2\ NaCl$$
$$Mg(NO_3)_2 + 2\ NaC_{15}H_{33}O_2 = Mg(C_{18}H_{33}O_2)_2 + 2\ NaNO_3$$
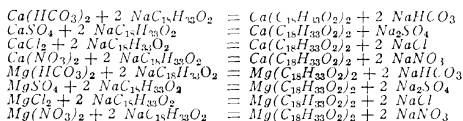
It will be observed that all of these reactions consist merely in an interchange of calcium or magnesium for sodium. The calcium (Ca) and magnesium (Mg) combine with the oleate radical ($C_{18}H_{33}O_2$) to form the insoluble soaps of calcium and magnesium. These insoluble soaps are sticky substances, commonly called "curds," and do not form a lather when shaken with water, as do sodium or potassium soaps. Furthermore, a sodium soap will not give a lather to the water so long as calcium and magnesium ions are in solution, because the oleate radical ($C_{18}H_{33}O_2$) immediately combines with the calcium to form the insoluble product. It is only after more soap than will combine with the calcium and magnesium has been added to the water, so as to leave an excess of soap (sodium oleate or its equivalent), that a lather will be formed. A standardized soap solution is, therefore, a means for quickly determining the total hardness of water.

It is also to be observed that one molecule of calcium carbonate (molecular weight 100) combines with the same amount of soap as does one molecule of calcium sulphate (molecular weight 136). The same is true for one molecule of calcium chloride, calcium nitrate, magnesium carbonate, magnesium sulphate, magnesium chloride or magnesium nitrate. Since 100 grains of calcium carbonate consumes the same amount of soap as does 136 grains of calcium sulphate, it represents the same amount of hardness. Likewise 100 grains of calcium carbonate represents an amount of hardness corresponding to a number of grains equal to the molecular weight of any other salt of calcium or magnesium It is, therefore, convenient to speak of hardness of water in terms of calcium carbonate, although it would be just as logical to speak of hardness in terms of calcium sulphate. A U. S. degree of hardness is one grain of hardness per gallon in terms of calcium carbonate.

The table of factors given on p. 734 can be used for converting hardness of water as commonly reported in water analyses to hardness in terms of calcium carbonate. If the analysis is reported originally in parts per million, these factors will convert the hardness so reported to parts per million in terms of calcium carbonate. Likewise if the analysis is reported in grains per gallon these factors will convert the hardness to grains per gallon in terms of calcium carbonate. If the analysis and hardness are given in parts per million they can be converted to grains per gallon by multiplying by .0583, or by dividing by 17.12.

Multiplying Factors to
Convert Hardness into Terms
of Calcium Carbonate

Calcium bicarbonate	$Ca(HCO_3)_2$	$\times$	.62
Calcium sulphate	$CaSO_4$	$\times$	.74
Calcium chloride	$CaCl_2$	$\times$	.90
Calcium oxide	CaO	$\times$	1.79
Calcium	Ca	$\times$	2 50
Calcium nitrate	$Ca(NO_3)_2$	$\times$	.61
Magnesium carbonate	$MgCO_3$	$\times$	1 19
Magnesium bicarbonate	$Mg(HCO_3)_2$	$\times$	68
Magnesium sulphate	$MgSO_4$	$\times$	83
Magnesium chloride	$MgCl_2$	$\times$	1 05
Magnesium nitrate	$Mg(NO_3)_2$	$\times$	68
Magnesium oxide	MgO	$\times$	2.48
Magnesium	Mg	$\times$	4.12

The application of these factors to a water analysis reported in the usual form is illustrated in the following, which also shows how the total amount of hardness actually reported in the water analysis differs from the total hardness in terms of calcium carbonate

	Parts per Million	Grs per U S Gal. Factor	In Terms of Calcium Carbonate Parts per Million	Grs per U. S. Gal.
Calcium carbonate	92	5 37 $\times$ 1.	92	5.37
Calcium sulphate	189	11 02 $\times$ .74	140	8 17
Magnesium carbonate	83	4 84 $\times$ 1 19	99	5 76
Magnesium chloride	20	1 17 $\times$ 1 05	21	1 23
	384	22.40	352	20.53
Silica	14	.82		
Iron oxide and alumina	4	.23		
Sodium sulphate	5	.29		
Sodium chloride	94	5.48		
Volatile and organic	117	6 82		
	618	36.04		

Observe that the silica, iron oxide, alumina, sodium sulphate and sodium chloride have not been converted into terms of calcium carbonate. It would, however, be possible to do this by taking into account their comparative molecular weights. We are here concerned only with hardness of the water and these substances do not impart hardness to the water. If the iron were present in appreciable amounts, as in the form of iron sulphate, it would give hardness to the water, but iron sulphate is not found in waters, excepting acid waters or those bordering on acidity. It would be impossible to report volatile and organic matter in terms of calcium carbonate, since the volatile and organic matter as reported are not definite chemical compounds with known molecular weights, but are combinations of substances which volatilize upon heating. Likewise total solids cannot be reported in terms of calcium carbonate because total solids is a summation of all the substances in solution and does not, therefore, have a definite molecular weight.

FILTRATION

The clarification of water by filtration is accomplished by passing the water through a sand bed consisting of grains suitably graded and sized, preceded, if required, by coagulation and sometimes by sedimentation. Filtration is essentially a screening and frictional resistance process. Suspended matter which is too large to pass through the interstices between the sand grains is strained out and retained on the surface of the filter bed, and

smaller. particles are retained by the bed through frictional resistance. Of other particles too fine to be removed by straining or frictional resistance, some are colloidal and can be removed after proper coagulation. Coagulation is generally accomplished by the precipitation of aluminum hydrate or iron hydrate obtained by feeding into the water aluminum sulphate, or iron sulphate with lime. The benefits of coagulation are accomplished in two ways:

First—The precipitation of aluminum hydrate or iron hydrate causes the small colloidal particles to combine to form larger particles, which are retained by the sand bed.

Second—The precipitated iron or aluminum hydrate itself forms a mat on the surface, with interstices smaller than those of the sand layer. This mat of very fine interstices therefore accomplishes a better screening or filtering than is obtained with sand alone.

Water containing more than the usual amount of suspended solids, as from streams containing much finely divided silt, should not be delivered directly to the filter bed, because with such waters the filter bed would be fouled too rapidly and would require back-washing too frequently. Waters of this class should settle from one to four hours, accompanied by coagulation, before delivery to the filter. The period of sedimentation and the kind of coagulation are determined by the character and amount of the suspended solids. The purpose of sedimentation is to reduce the work of the filter. Such solids as will settle out in from one to four hours can be removed more economically by sedimentation than by filtration alone.

When water flows through a filter, the coagulated solids are retained on the surface of the filter bed, where they in no wise interfere with perfect filtration, but, on the contrary, cause increased frictional resistance and afford a finer screening than when the filter is first placed in service; in fact, a filter is at its best just as its capacity begins to decrease.

When the solids accumulate on the surface of the bed to such an extent that the frictional resistance through the bed becomes excessive, say five pounds per square inch, it is generally found desirable to remove the retained solids by backwashing. The wash water is passed upward through the filter bed at a rapid rate, causing a "boiling" of the sand and carrying off the suspended matter. Sometimes it is desirable to supplement the back-washing with air agitation.

The chief distinction between pressure filters and gravity filters is that the former have a closed container designed to withstand the working pressure, so that ordinarily the use of pressure filters does not require additional pumping, whereas gravity filters have open containers, which make necessary additional pumping unless the water can flow by gravity from a settling basin to the filter, in which case the service pump picks up the filtered water from a clear-well chamber and pumps it to the storage tank and to the various points of use. If it is necessary to pump the water to a filter, it is generally advisable to install a pressure filter, for under these conditions the use of a gravity filter would make it necessary to pump the water twice.

The capacity of filters is dependent upon the character of the water to be filtered, and in general lies between two and four gallons per minute for each square foot of filter bed area. The more suspended solids in the water, the lower should be the rate of filtration.

CHEMICAL TREATMENT

Boiler Compounds.—The *Prime Movers Committee* of the *National Electric Light Association* reports the following analyses of commercial boiler compounds:

Comp No. 1. Water (loss 550° C) 71 47%
                 Silica 17 84%
                 Alkali Oxides as Sodium Oxide . 7 78%
                 Organic Matter 2 91%
Comp No 2 Water . . 58 39%
                 Silica (Insulator) 25 85%
                 Iron Oxide ... . Trace
                 Alumina . . . . . . None
                 Titanium Oxide .... None
                 Calcium Oxide . . . Trace
                 Magnesium Oxide . Trace
                 Chrome . None
                 Sulphuric Anhydride ... . None
                 Sodium Oxide 14 8%
Comp. No. 3. Caustic Soda 27 68%
                 Calcium Carbonate 2 14%
                 Organic Matter (probably logwood)... .. 32 03%
                 Water 38 15%
Comp No 4. Moisture 1 39%
                 Organic Matter . .. 2 73%
                 Aluminum Oxide 78 26%
                 Calcium Carbonate 11 13%
                 Calcium Oxide . . . 2 18%
                 Sodium Oxide 3 06%
                 Chlorine . ... Trace
                 Silica 0 30%
                 Magnesium Oxide 0 95%
Comp. No. 5 Water 56 45%
                 Silica 27 17%
                 Sodium Oxide 14 51%
                 Iron Oxide 0 81%
Comp No 6 Water 14 82%
                 Tannic Acid 9 00%
                 Non-tannic Organic Matter.. . .. . 40 69%
                 Soda Ash 35 49%
Comp. No. 7. Water 77.30%
                 Tannin 9 00%
                 Undefinable Organic Matter 8 06%
                 Silica 3 18%
                 Oxide of Iron and Alumina 2 09%
                 Lime 0 16%
                 Magnesia 0 14%
                 Alkali 0 11%
                 CO_2 .... 0 07%
Comp No. 8. Water 78 33%
                 Organic Matter ....
                 Non-tannin 7 51%
                 Tannin 7 74%
                 Soda Ash .... 5 3 %
                 Iron Oxide . . .. 1 1 %
Comp. No 9. Water . . . . 82.0 %
                 Organic Matter .. .. 0 1 %
                 Caustic Soda .... 3 3 %
                 Soda Ash .... 13 0 %
Comp No 10. Water 94 15%
                 Tannin Matter 0 43%
                 Non-tannin Organic Matter.... .... 3 65%
                 Sodium Carbonate 1 40%
Comp. No. 11. Water .. . . 83 0 %
                 Organic Matter .... 1 0 %
                 Soda Ash .... 16 0 %

Comp. No. 12. Soda Ash   .   .   .   . 38.8 %
                Tri Sodium Phosphate   . . .   . 61.2 %
Comp. No. 13. Water .   .   .   . 56 7 %
                Silica`   .   .   . . 27.2 %
                Sodium Oxide   .   .   .. .. 14.5 %
Comp. No. 14. Water   .   .   .   63 93%
                Silica .   .   .   . . 18 8 %
                Na_2O . .   .   .   . . 10 7 %
Comp. No 15   Water   .   .   . 61 6 %
                Organic Matter   .   .. 1 0 %
                Tri Sodium Phosphate.   . 37.4 %

ANALYSES OF COMMERCIAL SODAS

Comp No 16 Soda Ash—Sodium Oxide   60 7 %
Comp No. 17 Caustic Soda—Sodium Oxide   77 0 %
Comp. No 18 Tri Sodium Phosphate—Sodium Oxide   25 5 %
Comp No 19. Silicate of Soda—Sodium Oxide   13 7 %

COST OF COMPOUNDS AS COMPARED WITH SODA ASH

Boiler Compound Number	Soda Content Based on Soda Ash	Pounds Compound Equal to 100 lb. Soda Ash	Cost of Equivalent of 100 lb Soda Ash ‡
1	14 0%	700	$70 00
2	26 6%	368	36 80
3	38 8%	253	25.30
4	5 4%	1810	181 00
5	26 1%	375	37.50
6	35.5%	277	27 70
7	Contains no soda	.	.. .
8	5 3%	1840	184 00
9	13 0%	755	75 50
10	1 4%	7000	700 00
11	16 0%	610	61 00
12	65 7%	150	15 00
13	26 1%	375	37 50
14	19 2%	510	51 00
15	16 5%	610	61 00
16*Soda Ash	98 0%	100†	2 50
17*	99 0%	94†	2 35
18*	44 0%	455†	11 37
19*	24 6%	528†	13 20

*Commercial chemicals
†Weight based on market value and per cent purity
‡Based on 10c per lb. for compounds

Internal Treatment.—While this is essentially the same as the use of boiler compounds, it is regarded as a more scientific method in that commercial chemicals, such as soda ash, caustic soda or tri-sodium phosphate or a combination, are usually applied under a definite method of control. No attempt is made to treat out the bicarbonates, which are taken into the boiler and deposited through the giving off of carbon dioxide, with the precipitation of calcium carbonate according to the following reaction:

$$Ca(HCO_3)_2 + \text{heat} = CaCO_3 + H_2O + CO_2$$
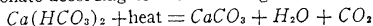
The chemicals fed to the boiler are calculated according to the amount of permanent hardness, including calcium sulphate, magnesium sulphate, chlorides, etc. The principal object of internal treatment is to convert the calcium sulphate to calcium carbonate, which gives assurance of forming a mud rather than a hard, dense scale. The application of soda ash or other treating compounds causes a precipitation of all of the hardness within the boiler, considerable suspended matter collects, and the use of soda as the

treating chemical is frequently the cause of violent foaming and priming. At plants where priming and foaming occurred with internal treatment, the installation of a water softener has stopped the priming and foaming tendencies, due to more regular feeding of chemicals and the elimination of suspended matter.

The method of feeding chemicals for internal treatment is ordinarily by gravity to an open heater at a constant rate. Such methods may cause operating disturbances due to disproportionate feeding.

A common method for determining the amount of reagent is to make a soap test of the boiler water for hardness; another is to test a filtered sample of boiler water for soluble calcium. A defect of the first method is that boiler water usually contains considerable caustic soda, which may cause an indication of soft water, even though hardness may be present. The second method overlooks the soluble calcium carbonate present in every boiler water. Other methods of control are based on maintaining the carbonate (CO_3) radical at a certain minimum concentration, depending upon the concentration of the sulphate (SO_4) radical. For instance, $R.$ $E.$ $Hall$ states that the formation of adherent anhydrite scale on the evaporating surfaces of a boiler operating at 185° C. (150 lb. gage pressure) is prevented by using soda ash to maintain the following condition in the boiler water:

$$CO_3/SO_4 > .0883$$

Sodium phosphate has at times been recommended instead of soda ash for the high pressures, in order to avoid the action of soda ash in partially breaking down into caustic soda and carbon dioxide under the influence of boiler pressures and temperatures. The higher the pressures the greater the conversion of carbonate to hydrate, which is also affected by the rate of steaming. Comparing carbonate with phosphate, $Hall$ states: "Because of the various factors that are effective in rendering the use of soda ash uneconomical or infeasible for the final conditioning of the boiler water, it is impossible to lay down any general rule as to operating pressures and ratings at which the change from soda ash to phosphate must be made It is doubtful whether the final conditioning with soda ash is economical or feasible at or above an operating pressure of 250 lb gage. If the makeup water is high in sulphate, or the rating high, the use of phosphate may be necessary at much lower pressures. However, if a copious blow-down with heat exchangers is the practice, soda ash may be satisfactory at higher pressures, although the loss of treating chemical seems unjustifiable." In the operation of hot process lime and soda softeners, however, it has been found that soda ash is satisfactory for pressures up to 375 lb. No trouble is experienced from the use of soda ash alone and the blow-downs are not above normal.

However, tri-sodium phosphate has been used for years as a constituent of boiler compounds and internal treatment and for conditions of very high pressures may have economical advantages over soda ash, as pointed out above. The chemical reaction involved in the precipitation of calcium sulphate is as follows ·

$$2Na_3PO_4 + 3CaSO_4 = 3Na_2SO_4 + Ca_3(PO_4)_2$$
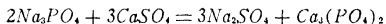
If it is desired to introduce the necessary phosphate and at the same time maintain a lower alkalinity that would be produced by the use of the tri-sodium phosphate, the di-sodium phosphate might be used, the chemical formula of which is Na_2HPO_4.

Where pressures and steaming rates are high, the complete precipitation of both temporary and permanent hardness within the steam unit becomes an almost insuperable objection to internal treatment for economic operation. Hard carbonate scale is formed, and priming and foaming tendencies will be materially increased Skimmers or deconcentrators, operated by pump or through the natural circulation of the water, have been applied in order to overcome this objection. Ordinarily they are placed on the operating floor and receive water from the surface in the drum, discharging clarified water back to the boiler through the mud drum Such apparatus handles a small portion of the water and does not completely clarify the concentrated boiler water.

Lime and Soda Ash Reactions.

—The reactions involved in the treatment of boiler feed water by a combination of lime and soda ash are discussed below.

$$Ca(HCO_3)_2 + Ca(OH)_2 = 2CaCO_3 + 2H_2O$$
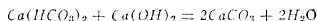
Calcium normal carbonate, formed as a result of the reaction between the calcium bicarbonate and the hydrated lime, is but slightly soluble and is therefore removed from the water as a precipitate, while no soluble salt remains to concentrate in the boiler.

$$CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4$$

The calcium normal carbonate, produced from the action of soda ash on calcium sulphate, is precipitated, while sodium sulphate, highly soluble in water, remains in solution as a neutral salt which will concentrate in the boiler but will not cause scale or corrosion.

$$CaCl_2 + Na_2CO_3 = CaCO_3 + 2NaCl$$

Calcium carbonate precipitated, sodium chloride remains as dissolved neutral salt.

$$Ca(NO_3)_2 + Na_2CO_3 = CaCO_3 + 2NaNO_3$$
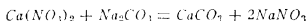
Calcium carbonate precipitated, sodium nitrate remains as dissolved neutral salt.

$$Mg(HCO_3)_2 + 2Ca(OH)_2 = Mg(OH)_2 + 2CaCO_3 + 2H_2O$$
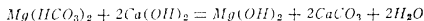
It would not be effective merely to convert magnesium bicarbonate to magnesium normal carbonate, because the latter is appreciably soluble even in hot water. Therefore, sufficient lime must be added to the water to convert all the magnesium to magnesium hydrate, which is but slightly soluble and hence effectively removed, while the lime is converted to calcium carbonate, which is also precipitated, no soluble salts being produced

$$MgSO_4 + Ca(OH)_2 = Mg(OH)_2 + CaSO_4$$
$$CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4$$
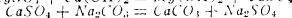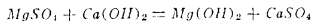
As a result of this double reaction when both hydrated lime and soda ash are used with magnesium sulphate, insoluble magnesium hydrate and calcium carbonate are precipitated, while the sodium sulphate formed concentrates in the boiler as a neutral salt The calcium sulphate exists only momentarily

$$MgCl_2 + Ca(OH)_2 = Mg(OH)_2 + CaCl_2$$
$$CaCl_2 + Na_2CO_3 = CaCO_3 + 2NaCl$$
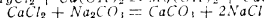
This treatment of magnesium chloride results in the precipitation of the calcium and magnesium, while the sodium chloride produced remains in the water as a neutral salt

$$Mg(NO_3)_2 + Ca(OH)_2 = Mg(OH)_2 + Ca(NO_3)_2$$
$$Ca(NO_3)_2 + Na_2CO_3 = CaCO_3 + 2NaNO_3$$
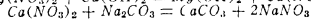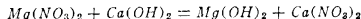
This double reaction for the treatment of magnesium nitrate results in the precipitation of the calcium and magnesium, while sodium nitrate remains dissolved in the water as a neutral salt.

Lime purchased for water softening should be specified as "hydrated lime containing not less than 90% calcium hydroxide," avoiding in particular lime containing more than 3% magnesium salts, and lime high in impurities which are not effective for water softening but which may be permissible

for other purposes for which lime is used. Lump lime should be avoided, as the lumps frequently contain unburned rock, which makes it difficult to weigh out the charge properly and which may damage the water softening mechanism.

Soda ash is composed of sodium oxide, Na_2O, 62.1 parts, and carbon dioxide, CO_2, 44 parts, combining to form sodium carbonate, Na_2CO_3, 106.1 parts. "58% soda ash" should be specified; this means that 58% of the product is sodium oxide, corresponding to 99.1% pure sodium carbonate.

Caustic Soda and Soda Ash Reactions.—The foregoing treatments are independent of the proportions of the various scale-forming solids, but to use successfully a combination of caustic soda and soda ash, the bicarbonates of calcium and magnesium in the water supply must be low enough so that the reactions between them and the caustic soda will not result in the formation of more sodium carbonate (soda ash) than is required to precipitate the calcium sulphate, chloride or nitrate.

$$Ca(HCO_3)_2 + 2NaOH = CaCO_3 + Na_2CO_3 + 2H_2O$$
$$CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4$$
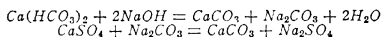
If sufficient caustic soda is fed, the calcium bicarbonate is transformed to insoluble normal carbonate, and sodium carbonate is produced, which is then available for the precipitation of calcium sulphate, chloride or nitrate, as for example in the above equation, which is the same as in the preceding section.

$$CaCl_2 + Na_2CO_3 = CaCO_3 + 2NaCl$$
$$Ca(NO_3)_2 + Na_2CO_3 = CaCO_3 + 2NaNO_3$$
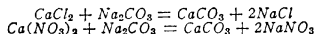
The reactions between the soda ash and calcium chloride and nitrate are also similar to the foregoing.

$$Mg(HCO_3)_2 + 4NaOH = Mg(OH)_2 + 2Na_2CO_3 + 2H_2O$$
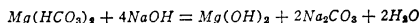
Magnesium bicarbonate treated with caustic soda is converted into insoluble magnesium hydrate, and the soda ash formed is available for the treatment of any calcium sulphate, chloride and nitrate.

$$MgSO_4 + 2NaOH = Mg(OH)_2 + Na_2SO_4$$
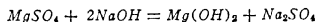
The treatment of magnesium sulphate with caustic soda differs from that with lime and soda ash, in that but one chemical reaction is involved, the products being insoluble magnesium hydrate and soluble, neutral, sodium sulphate.

$$MgCl_2 + 2NaOH = Mg(OH)_2 + NaCl$$
$$Mg(NO_3)_2 + 2NaOH = Mg(OH)_2 + 2NaNO_3$$
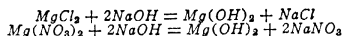
Caustic soda precipitates magnesium hydrate from either magnesium chloride or magnesium nitrate.

Caustic soda is composed of sodium oxide, Na_2O, 62.1 parts and water, H_2O, 18.016 parts, forming $NaOH$. For water softening, specify "76% granulated caustic soda delivered in barrels or steel drums," the 76% referring to the quantity of sodium oxide contained in the product and corresponding to 98% caustic soda. The granulated form, in receptacles which can be kept closed, is to be preferred to the solid blocks, which weigh about 600 lb.

Apparatus for Lime and Soda Ash Treatment: The Intermittent Cold Process.—Such a softener consists essentially of two or more large

sedimentation tanks, with pressure or gravity filters. When two tanks are used, the treated water is taken from one tank while the other tank is rapidly filled with raw water and chemicals A definite volume of water is treated with a definite weight of chemicals, assuring accuracy in proportioning The most common method of operation is to feed the chemicals at the time of first introducing the water and, after the tank has been filled, to agitate either by air or by mechanical stirring means This insures uniform fusion of the chemicals in the water, after which the chemical reactions follow. Since chemical reactions in cold water are sluggish, the treated water is allowed to stand for three to five hours, sometimes longer The precipitate is likely to be finely divided and a coagulant, such as aluminum sulphate or copperas or ferrous sulphate, is often added to assist the coagulation After sufficient settling, the water is drawn off through a swing pipe to the gravity or pressure sand filters, from which it passes to the feed water heater as boiler feed.

It is claimed that, with proper settling and time, intermittent cold process treatment will reduce the hardness below two grams per gallon. However, this depends largely upon the excess of chemicals used and upon the time of settlement The intermittent system is not now commonly used, because of the high initial cost of installation, and especially the amount of piping necessary and the great space occupied, and because it is now definitely recognized that treatment in the hot state is the more efficient.

Continuous Cold Process.—The continuous cold process lime and soda system is used chiefly where steam is not available, as at locomotive water stations and in ice plants where raw water ice is manufactured. The continuous cold process softener is usually designed to have a capacity of four hours or more, which is necessary in that the chemical reactions are always sluggish in the cold The method of proportioning chemicals is usually the same as that used in hot process softeners The reduction in hardness depends largely upon the excess of softening chemicals used.

The cold process softener is used in power plant work in softening water for cooling ponds where water recirculated through surface condensers is high in bicarbonates which might concentrate and deposit in the condensers.

Hot Process Water Softener.—In the hot process softener the raw water is first heated to within two to five degrees of the boiling point, or quite to the boiling point if the softener has a deaerating heater top. Treatment while hot has two important results:

1 The chemical reactions are almost instantaneous.

2 The precipitate formed is of such a nature that it readily settles, and inasmuch as it settles through boiling-hot water the viscosity of which is only about one-sixth that of water at $32°$ F, the efficiency of sedimentation is greatly improved as compared with cold water, and an additional coagulant is not needed.

The precipitates collect in the cone-shaped bottom of the sedimentation tank, from which they can be discharged through the blow-off connection. The heated water off-take funnel is so shaped that the precipitates continue in a downward path when the water turns upward into the funnel Although the water leaving the sedimentation tank is comparatively clear, it is further clarified by a filter, using a non-silicious filtering material which has the advantage over ordinary sand that it does not dissolve in the hot alkaline water, as does silica sand.

1   VALUE OF HEAT IN SOFTENING WATER
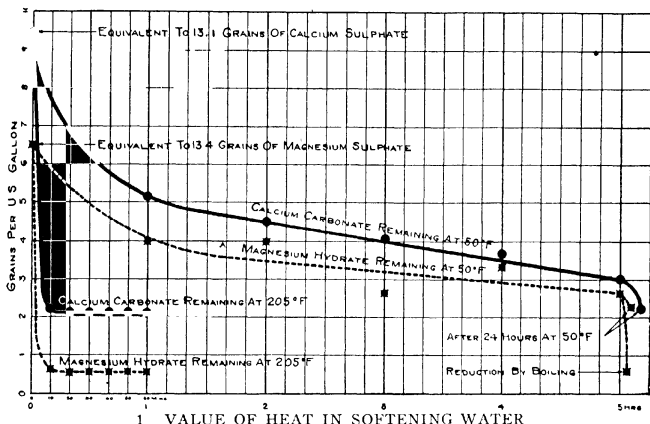
    Solid curves show Calcium Carbonate remaining in solution after treating Calcium Sulphate with Sodium Carbonate (Soda Ash)
    Dotted curves show Magnesium Hydrate remaining in solution after treating Magnesium Sulphate with Calcium Hydrate (Lime).
    In all tests the theoretical quantity of softening chemicals was used to combine with the scale forming solids.

Effect of Heat on Softening Reactions.—As shown in Fig. 1, chemical reactions for the treatment of sulphates are completed in less than ten minutes' time at a temperature of 205° F., but with cold water are not completed after several hours' treatment. Also, only about one-half as much of calcium and magnesium salts (scale-forming impurities) remain in the water after treatment hot as after cold treatment. The precipitate in a cold process softener is finely divided and settles slowly, while that from a hot process is in large flakes, which settle rapidly and act as a coagulant. Water from a cold process, later heated to 205° F., will deposit additional scale-forming impurities in the feed water heater, boiler feed pumps and pipe lines, the effect of heating water after softening instead of before being shown by the nearly vertical dotted line in the lower right hand of Fig. 1.

    Calcium and magnesium salts, which are the principal scale-forming impurities, are precipitated as calcium carbonate and magnesium hydrate, which have a low solubility, particularly in hot water, and still less in the presence of a small excess of sodium carbonate, say 1½ grains per U. S. gal. The products of softening may be precipitated to still lower limits, if the sodium carbonate is maintained in excess of the figure here recommended, but the balance between the excess softening chemical and the mud-forming impurities remaining in solution is a problem of the individual plant. When the heating is not sufficient to eliminate dissolved gases from water, before the addition of softening chemicals, it is necessary to add sufficient lime to remove the free CO_2 present, an excess being usually required with the cold process.
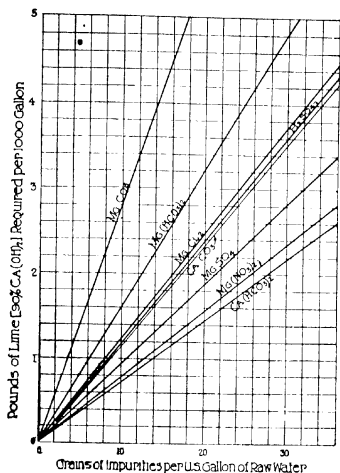
2. LIME REQUIRED AS REAGENT
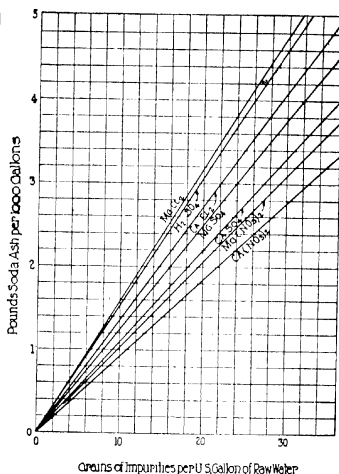
3. SODA ASH REQUIRED AS REAGENT

Amount of Chemicals Required.—Figs. 2 and 3 show the amounts of lime and soda ash theoretically required for the treatment of scale-forming impurities. The following examples show the method of calculation:

Water analysis, grains per U. S. Gal.	No 1	No 2	No. 3
Calcium carbonate, $CaCO_3$	9 92	11 41	
Calcium sulphate, $CaSO_4$	7 35		5 37
Magnesium sulphate, $MgSO_4$	6 42		2 27
Magnesium chloride, $MgCl_2$	29		
Sodium chloride, $NaCl$	1 46	1 69	6 48
Magnesium carbonate, $MgCO_3$		4 56	
Silica, SiO_2		42	1 17
Iron oxide and alumina		.26	.17
Sodium sulphate, Na_2SO_4		5 98	1 06
Organic and volatile		3 48	.82
Sodium nitrate, $NaNO_3$			1 05
Sulphuric acid, H_2SO_4			.06
	——	——	——
Total solids	25 38	27 80	18 45
Suspended matter	.23		
Lime required lb. per 1000 gal.	1 80	2 61	.23
Theo. soda ash required	1 68	0 00	.89
Additional soda ash	.21	.21	.21

For No. 1, the lime for treatment of the $CaCO_3$, $MgSO_4$ and $MgCl_2$ was calculated from Fig. 2, the scale forming $CaSO_4$ and non-scale-forming $NaCl$ requiring no lime. Soda ash for the $CaSO_4$, $MgSO_4$ and $MgCl_2$ calculated from Fig. 3, and additional soda ash allowed to produce an excess of 1½ grains per U. S. gallon. Scale-forming $CaCO_3$ and non-scale-forming $NaCl$ require no soda ash.

For No. 2, lime alone is required, to transform the $CaCO_3$ and $MgCO_3$, but the 0.21 lb. soda ash is added to make the water alkaline without the use of an excess of lime.

For No. 3, lime is required for the $MgSO_4$ and H_2SO_4, and soda ash for the $CaSO_4$, $MgSO_4$ and H_2SO_4.

The Lime-Barium Softener.—The chemical reactions used in the lime barium softener are as follows:

(1) $Ca(HCO_3)_2 + Ca(OH)_2 = 2CaCO_3 + 2H_2O$
(2) $CaSO_4 + BaCO_3 = BaSO_4 + CaCO_3$
(3) $Na_2SO_4 + BaCO_3 = BaSO_4 + Na_2CO_3$

Saturated lime solution is used rather than milk of lime as in lime and soda ash softeners. The milk of lime is made up in a saturator and is fed to the incoming water in proportion to the amount of water coming through the softener. This provides for the first reaction and results in the precipitation of the temporary hardness or carbonates. After this reaction is completed, the water passes through a bed of barium carbonate, which, while fairly insoluble, dissolves sufficiently to precipitate the sulphates The calcium sulphate is converted to barium sulphate in accordance with reaction (2), while sodium sulphate is converted to sodium carbonate as indicated in reaction (3).

The principal advantage claimed for this system is that precipitation of the sulphate hardness is effected without the formation of sodium sulphate, as with lime-soda and zeolite softeners. This lessens blowing down of the boilers and produces cleaner steam. The principal objection is that the cost of barium carbonate is so high that its use is generally prohibitive. Also, sulphates are entirely removed while at the same time sodium carbonate may be introduced into the boiler, depending upon the amount of sodium sulphate in the raw water supply, so that the caustic embrittlement condition may result. This type of apparatus has been applied in the Southwest, where the sulphate hardness is extremely high

Zeolites.—Various compounds, all of which are bi-metal silicates, have the property of removing calcium and magnesium from water. They differ as to chemical composition, method of preparation and amount of softening that may be accomplished by a given volume of the material. The chemical principles involved and the degree of softening obtainable are much the same in all cases. For waters of exceedingly low hardness it is sometimes desirable to use a natural zeolite of an exchange value of approximately 2700 grains per cu. ft. For waters very high in hardness, and where it is desirable to use small containers, a zeolite of higher exchange value, approximately 7500 gr. per cu ft., may be used The degree of softening accomplished by either mineral is essentially the same.

The exchange value of the zeolite and the depth of bed determine the capacity obtainable with any given diameter of container. For convenience the exchange value of a zeolite is generally based upon the cubic foot as a unit. The pound is not so good a unit because the same zeolite may not always contain the same amount of moisture.

The exchange value of a zeolite is measured by the amount of hardness that it will remove between successive regenerations with salt, while delivering water of zero hardness by the soap test. This is dependent to some extent upon the rate at which the water is passed through the zeolite bed, although generally speaking, the rate is not a limiting factor, but ordinarily can exceed the actual requirements without lowering the exchange value.

Zeolite removes hardness from water much as a sponge absorbs water. Until the pores of the sponge become filled, no water will pass through it, but once the pores of the sponge are satisfied, any additional water delivered

to the .sponge passes through, or displaces an equal amount of water pre-
viously absorbed by the sponge.

   Zeolite Water Softeners —As hardness is commonly expressed in grains per U. S.
gallon in terms of calcium carbonate, the exchange value of a zeolite may conveniently
be defined as the grains hardness in terms of calcium carbonate that one cubic foot will
remove between regenerations   For zeolite made from green sand or glauconite, a rate
higher than 2700 cannot safely be used   Some of the synthetic zeolites have initial
exchange values as high as 10 000 to 12 000, but it is not safe to base capacities of
zeolite softeners on these higher ratings because of their tendency to fatigue with use.
   Let us assume that the water has a hardness of 12 gr. per gal in terms of calcium
carbonate, that the peak requirement for softened water is 12,000 gal per hr. and
that the total requirements for 24 hrs. with a light night load will not exceed 100,000
gal.   These requirements could be served by a double unit installation, each unit
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600000/4500 = 133 cu. ft   The depth of bed preferred is 3 ft. 6 in , although occa-
sionally 4 ft. depth of bed is used, at other times 3 ft. depth.
   The size of the container can also easily be determined from the area of the bed,
which must be 133/3 5 = 38 sq ft.   This requires a 7 ft. diameter container.
   With a bed 4 ft deep, the area required is 133/4 = 33 2 sq. ft., corresponding to
6 ft. 6 in. diameter.
   A softener using zeolite with an exchange value of 2700 grains hardness per
cu. ft. would require 600000/2700 = 222 cu. ft.   For a 3 ft 6 in. bed this calls for a
9 ft. diameter container.

   Sometimes the peak capacity of the softener is stated, with the further
statement that the equipment has a daily capacity of, say, 100,000 gal.
Stated this way, the conditions might be met with a container of half the
size figured above, by making four regenerations per day instead of two.
Such frequent regenerations throughout the day are, however, generally
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will soften between regenerations.

   With the better zeolites, when hardness begins to show, it builds up
rapidly, so on the average a very soft water is obtained if regeneration is
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a corresponding amount of sodium.   After a definite amount of water has
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Lead Lined
Mixing Box

Water
Storage
Tank

Differential
Pressure

Calibrated
Tank

Acid
Proportioner

Differential Pressure Line

Proportioned
Acid
Solution

Raw Water
Orifice Plate

Lead Lined
Acid Tank

Circula
ling
Pump

Feed
Pump

Solution
Level Gauge

ACID FEEDING EQUIPMENT FOR ZEOLITE SOFTENER

Acid Treatment.—To lower the bicarbonate content of zeolite-softened water it is sometimes treated with sulphuric acid, which transforms some of the sodium carbonate to sodium sulphate, thus giving a more favorable ratio of sodium carbonate to sodium sulphate from the standpoint of embrittlement. Where sulphuric acid treatment is desired, acid-feeding equipment, as shown above, can be used for proportioning the acid automatically in accordance with the flow of water.

Lime Treatment.—If the water is very high in carbonates, it may be good economy to give a lime treatment or a combined lime and soda treatment, the chemicals for which, as a rule, will cost less than the salt required for regeneration. The lime treatment has the further advantage with high carbonate waters that the sodium carbonate after zeolite treatment will be less.

Deaeration.—Where zeolite softened water is to be used in boilers or is to be heated and subsequently distributed through iron or steel pipes, a deaerating heater should be installed in order to expel dissolved oxygen and thus prevent oxygen corrosion or rusting. This is particularly required with a zeolite softener, as water softened to zero hardness will not deposit lime or other protective coating on the metal.

Water softened by the zeolite method is more likely to cause corrosion than is the untreated water or the same water treated by the hot process lime-soda method.

Treatment of High Alkaline Waters with Sulphuric Acid.—Certain well waters have the unusual combination of very low hardness with a considerable amount of sodium carbonate alkalinity, due in some cases to passage through beds of natural zeolite, where the calcium and magnesium are exchanged for sodium. Frequently these waters are also low in sodium sulphate and sodium chloride. The artesian well water of which the analysis is given below will not form scale in the boilers, but would cause high concentration of sodium carbonate. The best way to establish the desired ratio between sodium carbonate and sodium sulphate is to treat the water with sulphuric acid, thereby changing over some of the sodium carbonate to sodium sulphate,

$$Na_2CO_3 + H_2SO_4 = Na_2SO_4 + H_2CO_3$$

Heating in an open feed-water heater, preferably of the deaerating type, will then break up the carbonic acid, driving off dioxide gas.

$$H_2CO_3 + heat = H_2O + CO_2$$
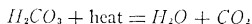
After treatment with sufficient sulphuric to neutralize 10 gr. of sodium carbonate alkalinity, leaving 2 50 gr. per gal., the water would have the analysis given in the second column below.

HIGH ALKALINE WATER TREATED WITH SULPHURIC ACID

	Raw Gr per U S. Gal	Treated Gr per U S. Gal
Calcium Carbonate	.49	.49
Magnesium Carbonate	.25	.25
Sodium Carbonate	12 50	2 50
Sodium Chloride	.39	.39
Sodium Sulphate	64	14.04
Iron Oxide and Alumina	1 18	.18
Silica	1 56	1.56
Volatile and Organic	1 52	1 52

This requires approximately 1.3 lb. of sulphuric acid per 1000 gal. of water, which can be fed by an automatic proportioning device, producing a non-corrosive water.

The effect of sulphuric treatment on water from a zeolite softener is given in the following table by *A. H. White, J. H. Walker, E. P. Partridge* and *L. F. Collins.* It is interesting to note the elimination of the CO_2 and O_2 by passing the feed water through a deaerating heater.

	Raw Water	After Zeolite	After Acid Feed	After Deaerator	In Boiler	Steam
Temperature, °F.	40.0	40 0	40.0	215.0	365.0	365.0
Pressure, lb. ga.	45.0	7.5	....	.. .	155.0	....
pH value	7.6	8 6	6 4	8 5	....	5.4
CO_2 (free)	1.8	....	18 1	0.0	0.0	25.0
O_2 c.c. per liter	6 03	6 03	6.03	.016	....	.044
$NaHCO_3$	0.0	120 0	60 5	38.0	....	.. .
Na_2CO_3	0 0	0 0	0 0	14.2	174 0	....
Na_2SO_4	0 0	30.0	81 0	....	1500.0	....
$NaOH$	0.0	0.0	0.0	0.0	360.0	....
Total alkalinity as Na_2CO_3.	...	...	...	...	650.0	....
Na_2SO_4/total alkalinity	....	...	..	...	2.3	....
SO_4/CO_3	...	..	...	...	10.0	....

Quantities in parts per million unless otherwise stated.
Acid feed—35 parts of 100% H_2SO_4 per million parts of water treated.

COMPARISON OF WATER SOFTENING METHODS	Raw Water Gr. per gal.	Water After Treatment by Hot Lime-Soda Process Gr. per gal.	Water After Treatment by Zeolite Process Gr. per gal.	Water After Treatment by Lime-Barium Process Gr per gal.
Calcium Carbonate	5.38	.5	.3	1.5
Calcium Sulphate	6.88			.5
Magnesium Carbonate	5.20			1.0
Barium Carbonate	.			.4
Silica	.90	.9	.9	.9
Iron Oxide and Alumina	.20	.2	.2	.2
TOTAL INSOLUBLE SOLIDS	18.56	2.6	1.6	4.5
Sodium Sulphate	.35	7.5	7.5	.35
Sodium Chloride	2.34	2.3	2.3	2.34
Sodium Carbonate	.	1.5	11.9	.
TOTAL SOLUBLE SOLIDS	2.69	11.3	21.7	2.69
TOTAL SOLIDS	21.25	13.9	23.3	7.19
EFFECT OF FEEDING TO BOILERS	Large amount of scale would form.	Boilers would be protected from scale Total hardness lower than with lime-barium Sodium sulphate increased	Boilers would be protected from scale Total hardness lower than with lime-barium Sodium sulphate increased	Total hardness reduced, but not as low as with hot lime-soda or zeolite. Sodium sulphate not increased Hard scale formed unless there is excess of sodium carbonate.

COST OF CHEMICALS

The cost of chemicals for treating a water of the analysis above given are as follows for the respective processes'

HOT LIME-SODA

Calculated on providing an excess of 1¼ gr. soda ash per gal.; no excess lime:

2.07 lb. 90% effective calcium hydrate @ ¾c = 1.55c
1.0 lb. soda ash @ 1½c = 1.50c

Total cost per 1000 gal..... 3.05c

ZEOLITE

Calculated on providing ¼ lb. salt per 1000 gr. of hardness, in terms of calcium carbonate.

8.3 lb. salt @ ½c = 4.15c

4.15c

LIME-BARIUM

Calculated on providing 25% excess*
barium carbonate

2.07 lb. 90% calcium hydrate @ ¾c = 1.55c
1.77 lb. barium carbonate @ 2½c = 4.42c

5.97c

*Whereas special equipment has been proposed with a view to minimizing the waste in feeding barium, wastage will probably be not less than 25% of the theoretical requirements if total hardness is to be reduced as low as given above. The reason is that barium carbonate is rather slowly soluble, and some of it will mix with the precipitated calcium and magnesium carbonates and be carried off with the sludge.

Comparative Advantages of Hot Process, Zeolite, and Lime-Barium Treatment.—The accompanying tables show, for a raw water supply of average analysis, the character of the water to be expected after treatment by the hot lime-soda process, the zeolite process and the lime-barium process, also the cost of treatment.

The lime barium treatment lowers the hardness of the given water considerably, but will not completely prevent the formation of hard scale in the boiler. Its advantage is that the sodium sulphate is not increased in proportion to the calcium sulphate present, as must be expected with both the hot process and the zeolite treatments. The total hardness or insoluble solids of the water cannot be reduced by the lime barium treatment (hot or cold) as low as by either of the other methods, particularly if carried out with cold water. Furthermore, the hardness remaining after the lime-barium treatment will solidify in the boiler as hard scale unless excess sodium carbonate is fed to supplement the treatment, or unless the raw water contains a considerable amount of sodium sulphate, so that a portion of the sodium sulphate will be transposed to sodium carbonate. In the latter event the sodium carbonate will concentrate in the boiler, just as will a small excess fed with the hot process treatment, and under this condition hard scale can be prevented. If, however, the water does not contain appreciably any more sulphate than will be required to combine with the calcium and magnesium after first satisfying the carbonate radical, the barium treatment will not produce sodium carbonate to prevent the formation of hard scale in the boiler and it becomes necessary to add sodium carbonate.

Blow-down losses with the three different methods are determined by the permissible concentration of solids in the boiler. The higher the concentration that may be carried the lower will be the blow-down losses with any treatment. The maximum concentration permissible depends upon a number of conditions such as the rate at which the boilers are fired, the character of the load, the type of boiler, etc.

For purposes of comparison, assume that the boilers will operate without priming with a total concentration of 250 gr per gal, including the soluble solids, such as sodium salts, and also suspended matter.

It will also be assumed that from the standpoint of causing priming, one grain of suspended matter is equivalent to one grain of sodium salts in solution. Whether or not this is actually true is questionable, and it certainly is qualified to some extent by the character of the solids. Authorities disagree as to which solids are most conducive to priming. Some contend that suspended solids have most influence, others the sodium salts. All agree, however, that both suspended solids and sodium salts, if sufficiently high, will cause priming, and that large amounts of either will cause boilers to prime when relatively small amounts of the other are present. Water treated by the zeolite process is lowest in insoluble solids, i. e., mud-forming salts, but also highest in soluble salts (sodium salts). On the other hand, the insoluble solids are highest with the lime-barium treatment, while the soluble salts are lowest with this treatment. The hot process treatment comes midway between the zeolite and the lime-barium treatments. If suspended solids are worse than sodium salts, grain for grain, this comparison is slightly unfavorable to the zeolite softener, but gives the lime-barium treatment a corresponding advantage. If soluble solids are more likely to cause priming than suspended solids, this comparison is unfavorable to the lime-barium treatment but gives the zeolite treatment the advantage.

Putting both soluble solids and insoluble solids on the same basis, from the standpoint of priming, is for all practical purposes a sufficiently fair basis. In this comparison we are also assuming that the hardness resulting from lime-barium treatment will not form scale in the boiler, but will come down as a suspended solid, as with zeolite and hot process treatment. As a matter of fact, for water as represented by analysis marked "Raw water," and for reasons above given it will be necessary to add possibly ½ to 1 gr of sodium carbonate per gal to the lime-barium treated water, after softening to prevent formation of hard scale. This further increases the cost of the lime-barium treatment by the cost of the soda ash required and correspondingly increases the soluble solids, so that the comparison gives the lime-barium treatment an undue advantage in this respect.

The amount of blowing down required in order to hold the concentration of the boiler water down to 250 gr. per gal, including the soluble and suspended solids, is calculated by dividing the total solids of the water after softening by the maximum concentration, namely, 250.

Whether the 94 gr. of soluble solids with 156 gr. of suspended solids, with lime-barium treatment, will have a greater or lesser tendency to cause the boiler to prime than the 233 gr of soluble salts and 17 gr. of suspended solids resulting from zeolite treatment, is a question that may be open to argument, but probably both waters would act much alike.

PERCENTAGE OF BLOW-DOWN: TOTAL CONCENTRATION 250 GR. PER GAL.

Hot Lime-Soda	Zeolite	Lime-Barium
13.9÷250=5.55% of water fed to boiler	23.3÷250=9 35% of water fed to boiler	7 19÷250=2.87% of water fed to boiler.
Soluble solids ....203 gr. per gal.	Sodium salts ....233 gr. per gal.	Soluble solids ....94 gr. per gal.
Suspended solids ...... 47 gr. per gal.	Suspended solids .... 17 gr. per gal.	Suspended solids ......156 gr. per gal.
250 gr. per gal.	250 gr. per gal.	250 gr. per gal.

BLOW-DOWN TO EVAPORATE 10,000 G. P. H. OF WATER

Hot Lime-Soda	Zeolite	Lime-Barium
$10,000 \times 5.55 \div (100-5\ 55)=589$ g.p.h $=4,900$ lb./hr.	$10,000 \times 9\ 35 \div (100-9\ 35)=1,030$ g.p.h $=8,600$ lb./hr.	$10\ 000 \times 2\ 87 \div (100-2\ 87)=296$ g.p.h $=2,460$ lb/hr

DAILY BLOW-DOWN LOSS, WITH COAL AT $5 00 PER TON. 14,300 BTU PER LB., 70% BOILER EFFICIENCY

With 60° feed......$\dfrac{4\ 900 \times 310 \times 24 \times 5}{14,300 \times 0\ 70 \times 2\ 000} = \$9\ 10$ $\dfrac{8\ 600 \times 310 \times 24 \times 5}{14,300 \times 0\ 70 \times 2\ 000} = \$16\ 00$ $\dfrac{2\ 460 \times 310 \times 24 \times 5}{14,300 \times 0\ 70 \times 2\ 000} = \$4\ 60$

135° feed......$\dfrac{4\ 900 \times 235 \times 24 \times 5}{14,300 \times 0\ 70 \times 2\ 000} = \$6\ 90$ $\dfrac{8\ 600 \times 235 \times 24 \times 5}{14,300 \times 0\ 70 \times 2\ 000} = \$12\ 10$ $\dfrac{2\ 460 \times 235 \times 24 \times 5}{14,300 \times 0\ 70 \times 2\ 000} = \$3\ 50$

210° feed......$\dfrac{4\ 900 \times 160 \times 24 \times 5}{14,300 \times 0\ 70 \times 2\ 000} = \$4.70$ $\dfrac{8\ 600 \times 160 \times 24 \times 5}{14,300 \times 0\ 70 \times 2\ 000} = \$8.25$ $\dfrac{2\ 460 \times 160 \times 24 \times 5}{14,300 \times 0\ 70 \times 2\ 000} = \$2\ 35$

DAILY COST OF CHEMICALS

$\$.0305 \times 10,589 \times 24 \div 1,000 = \$7.75$ $\$.0415 \times 11\ 030 \times 24 \div 1\ 000 = \$10\ 95$ $\$.0597 \times 10,296 \times 24 \div 1,000 = \$14\ 75$

DAILY COST OF BLOW-DOWN AND CHEMICALS

	Hot Lime-Soda	Zeolite	Lime-Barium
With 60° feed..	$16 85	$26 95	$19 35
135° feed	$14 65	$23 05	$18 25
210° feed	$12 45	$19 20	$17 10

CAPITALIZED VALUE OF YEARLY SAVING BY USE OF HOT LIME-SODA, OVER ZEOLITE, AT 10%

With 60° feed.. ... $(26\ 95-16\ 85) \times 300 \div 0\ 10 = \$30,300$
135° feed.. ... $(23.05-14\ 65) \times 300 \div 0\ 10 = \$25\ 200$
210° feed.. ... $(19.20-12\ 45) \times 300 \div 0\ 10 = \$20\ 250$

CAPITALIZED VALUE OF YEARLY SAVING BY USE OF HOT LIME-SODA, OVER LIME-BARIUM, AT 10%

With 60° feed... ... $(19\ 35-16\ 85) \times 300 - 0\ 10 = \$7,500$
135° feed.. ... $(18\ 25-14\ 65) \times 300 - 0\ 10 = \$10\ 800$
210° feed.. ... $(17\ 10-12\ 45) \times 300 - 0\ 10 = \$13,950$

This shows the inadvisability, from a dollars-and-cents standpoint of using a zeolite softener for such water, assuming that the initial costs of the zeolite and the lime-soda process are the same, which is probably correct for a plant of this size.

This shows an economy in the lime-soda over the lime-barium process, even if initial investments were the same. As a matter of fact, the lime-barium would cost more, because the barium sulphate formed settles slowly and requires large sedimentation tanks and filters.

The amount of heat lost in blowing down depends upon the boiler pressure and upon the initial temperature of the boiler feed supply For comparison, the boiler pressure is assumed at 150 lb per sq in gage and the temperature of make-up water as 60° F., total evaporation is assumed to be 83 300 lb per hr equivalent to 10,000 g p h. If the makeup were fed directly to the boilers at 60°, the loss per lb. of blow-down would be as in the first line below If it were heated to 210° with surplus exhaust steam, the loss would be as in the third line If it were heated to 210° F. with bled steam, which has done about half as much work as it could if expanded to the condenser, the loss can be calculated on the basis of an assumed feed temperature of (60 + 210) − 2 = 135° F, as in the second line

Heat of liquid at 150 lb pressure . . 338 *BTU*
Loss per lb of blow-down
    With 60° feed . . . 338−28 = 310 *BTU*
        135° feed . . 338−103 = 235 *BTU*
        210° feed . . . . 338−178 = 160 *BTU*

While the lime-barium process does reduce to a minimum the soluble sodium sulphate in the softened water the insoluble solids are in general greater than with the hot lime-soda process, and the cost of chemicals is more than twice as great. While less blowing down is required the annual cost of operating a 10 000 g p. h, plant, taking into account relative blow-down losses, would be from $700 to $1300 greater with the lime-barium process than with the hot lime-soda process, and the initial cost would also be greater

The advantages of barium have not been great enough to justify its high cost, and the barium treatment has not, therefore, made appreciable headway either in this or in foreign countries In this country there are comparatively few lime-barium treatment plants. In the 1926 report submitted by the *Vereinigung der Grosskesselbesitzer*, a summary is given of the chemical treatments used for boiler feed water by members of the association.

Of a total of 2849 plants investigated 2117 used either the lime-soda treatment or soda ash alone, 235 provided no treatment at all and 142 used evaporators leaving only 355 plants for all other treatments combined, of which only six used the lime-barium treatment. Most of the others used zeolite or lime and zeolite combined.

The lime-barium treatment has made no greater headway in Germany than in the United States, which is to be expected, considering that any advantages to be gained are not worth the additional cost

The artesian well water described in preceding paragraphs has, when treated by the hot process softener five times as much sodium sulphate as sodium carbonate, thus complying with the *A S M E. Boiler Code* for pressures higher than 250 lb

After zeolite treatment the ratio of sodium sulphate to sodium carbonate is 7 5 to 11.9, considerably less than that demanded for 150 lb. pressure and very much less than demanded for higher pressures.

To correct this relation of sodium sulphate to sodium carbonate, were a zeolite softener used, it would be necessary to treat the softened water with sulphuric acid or to feed a larger amount of sodium sulphate If the water were treated with lime and barium alone no sodium carbonate would be added to the boiler, but without question hard scale would form If a small amount of sodium carbonate were fed to concentrate in the boiler and to prevent hard scale formation, the reduced amount of sodium sulphate would permit only a very small amount of sodium carbonate to be fed. Accordingly, from the standpoint of embrittlement of boiler plate, and on the basis of information now available, the hot process treatment with lime and soda ash is the best.

Testing Softened Water.—The following directions are issued by the *Cochrane Corporation* for the testing of water treated in Cochrane softeners, but are applicable to any system treating water at a temperature of 205° F. or higher with lime and soda ash.

A graduated measuring burette (8) (p. 754) is filled to approximately the zero line with twentieth normal sulphuric acid ($N/20$ H_2SO_4), which is a standardized solution containing 2.4519 grams of pure sulphuric acid per liter of distilled water, obtainable from chemical supply houses. A 100-ml. sample of the treated water is taken in the measuring flask (2) (taking care to exclude any precipitate which may have settled in the sampling flask) and placed in the testing cup (3), and to this is added two drops of phenolphthalein solution containing 5 grams of phenolphthalein crystals per liter of denatured alcohol. Acid is gradually added from the burette,
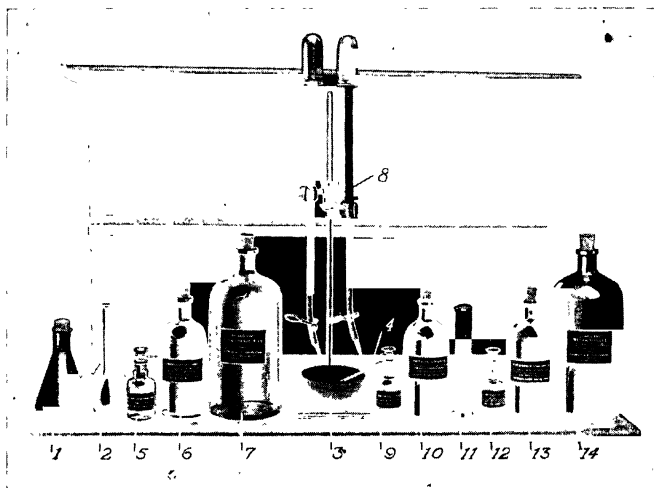
APPARATUS FOR TESTING TREATED WATER

1. Sampling flask.
2. 100 milli-meter measuring flask.
3. Test cup.
4. Glass stirring rod.
5. Dropping bottle containing phenol-phthalein (Ph) test solution
6. Stock supply of phenolphthalein solution.
7. Bottle of standard $N/20$ sulphuric acid for testing.
8. Burette with burette cap, held in position by burette clamp and stand.

9. Dropping bottle containing methyl orange ($M. O.$) testing solution.
10. Bottle containing stock supply of methyl orange testing solution.
11. Graduate cylinder.
12. Dropping bottle containing potassium chromate solution
13. Stock supply of potassium chromate solution
14.—Bottle containing supply of silver nitrate solution.

while stirring with the rod (4), until the pink weakens and disappears, and the ml. of acid taken from the burette recorded as the "Ph. value." Two drops of methyl orange solution, containing 1 gram of methyl orange crystals per liter of distilled water, are then added to the same sample, turning it yellow, acid is added until an orange tint is obtained, and the total amount of acid which has been added to the sample is recorded as the M.O. value. The chart on p. 755 gives the interpretation of these two values. A combination falling within the area A, as Ph. 1.4 and M. O. 3.1, indicates correct chemical treatment. If it falls within the area E, as with Ph. 0.4 and M.O. 4.4, the lime must be increased, but it is impossible to determine whether the soda ash must be altered until the lime has been so changed as to bring the intersection within one of the other areas.

Where a combination of caustic soda and soda ash is used, substitute the words "caustic soda" for "lime" in the chart.
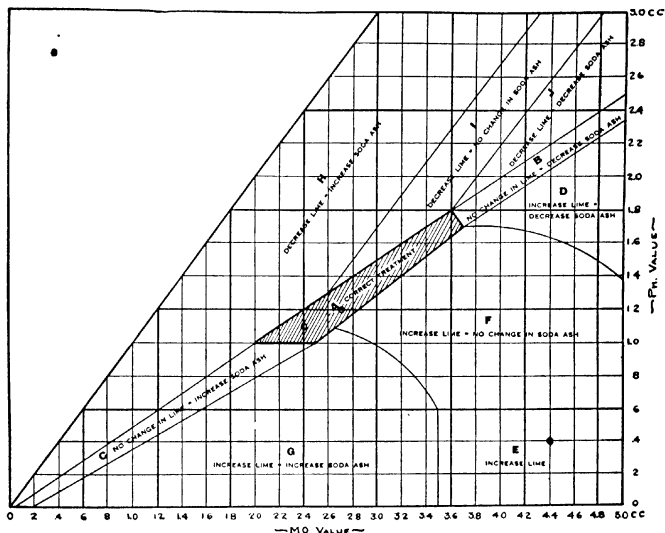
QUALITATIVE CHART FOR CORRECT CHEMICAL TREATMENT OF
WATER

The chart on p. 757 gives the proper changes in lime and soda ash
feed. Ph. 1.0 and M.O. 2.40 are considered the theoretically correct result,
although certain waters will be best treated with test readings slightly
lower, and all readings falling within the area "Correct chemical treat-
ment" will protect the boilers from scale and corrosion. Lines referring
to lime are at 35° with the horizontal, those referring to soda ash are
curves or 55° lines. The following readings from the chart are typical:

Ph.	M.O.	Change in soda ash, lb. per 1000 gal.	Change in lime, lb. per 1000 gal.
1.0	3.4	Decrease 0.1	Increase 0.3
1.8	3.8	Decrease 0.6	None
2.4	3 7	None	Decrease 0.23
2.1	3.0	Increase 0.45	Decrease 0.25

For certain conditions, it may be possible to carry slightly lower test
readings than called for. To determine this, draw a sample from the
water column of each boiler after blowing down thoroughly. After
cooling and settling, place a 100-ml. sample in the testing cup, add two
drops of methyl orange solution, and add acid from the burette, drop by
drop, until the orange tint is first obtained. The number of ml. of acid
required, multiplied by 1.5, gives the "total alkalinity," expressed in terms
of grains of sodium carbonate per gallon. If the softened water was
properly treated, the total alkalinity will represent the sodium hydrate,

magnesium hydrate, sodium carbonate and calcium carbonate in solution, all in terms of sodium carbonate, and the magnesium hydrate and calcium carbonate in solution, even after concentration, will be relatively small. If the total alkalinity in each boiler is regularly above 30, the chemical charge may be slightly decreased, even if the test readings fall a little below those called for on p 755. The M.O values must continue to be twice or slightly more than twice the Ph, even if it is found possible to carry the latter below 1 ml. If the total alkalinity in any boiler is less than 20, it is not safe to reduce the chemical charge in order to obtain readings lower than the chart calls for, but this will not require increasing the charge to obtain higher readings If all the test readings obtained fall above the lowest limit for correct treatment, the boilers will be protected from new scale and corrosion The low alkalinity may be on account of the old scale in the boiler, or because the boiler is blown too much to permit concentration to 20 grams alkalinity.

To test for concentration of soluble salts, take a 100-ml sample from the water column after blowing down, add one drop of phenolphthalein solution (turning it pink) and add sufficient $N/20$ acid from the burette to remove the pink color. Add four drops potassium chromate indicator, containing 200 grams of potassium chromate crystals to a liter of distilled water, then add, drop by drop, from a burette, "standardized" silver nitrate containing 4.976 grams pure $AgNO_3$ per liter of distilled water, until a permanent reddish precipitate forms, giving a slight tinge to the sample. The number of ml. of silver nitrate required is the number of grains of sodium chloride per gallon of water. Multiply this by usual ratio of total solids in solution to the sodium chloride, as determined by previous analyses of concentrated boiler water from the same source of supply. The concentration permissible can be determined by a comparison of such readings with a record of troubles encountered from excessive moisture in the steam, such as sudden drops in superheat temperatures, trouble with engine lubrication or deposits in superheaters and steam pipe lines, or by noting the quality of steam corresponding to various concentrations, by a throttling calorimeter, or chemical tests on samples of condenser steam

Boiler Operation with Softened Water.—All scale should be removed from the tubes and tube sheets of boilers before a water softener is started, as otherwise the softened water will loosen the old scale, with a possibility of burning out boiler tubes or the crown sheet, and there will be a tendency toward foaming and priming. The operator cannot, of course, control overload, variable loads or high pressure, all of which are conducive to foaming. Solid matter in the water, due to mud or organic matter originally suspended, or to solids precipitated from the water by heating in the boiler, may form as a scale on the inner surfaces of the boiler, as sludge on the bottom of the mud drum, or as scum on the water surface in the steam drum, producing foaming. An efficient water softener will reduce all of these to the minimum, if started with clean boilers, but, if started with boilers which are heavily scaled, the softened water will loosen the old scale, which will collect in the bottom of the boiler or in the mud drum, and as a scum which may produce foaming. With clean boilers, the more efficient a softener is in removing solid matter or dissolved scale-forming impurities from the water, the less will be the danger from foaming.
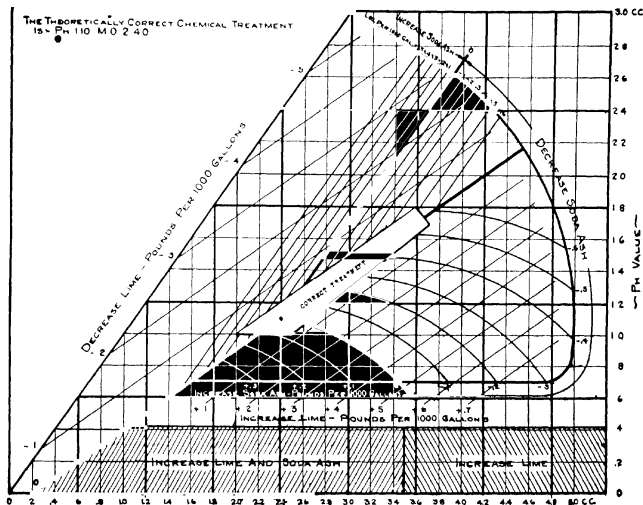
QUANTITATIVE CHART FOR WATER TREATMENT

When the maximum permissible concentration of soluble salts with which the boilers will deliver dry steam has once been determined for a given installation, they must be blown down enough to keep the concentration below this point. If the firing is not uniform, some of the boilers may carry little or none of the load at times, which means that the remainder of them will be overloaded and, therefore, will have a greater tendency to foam. The water level should be carried as low as possible to protect the tubes, leaving a good steam space above the water. If old scale is not removed before beginning to feed softened water, it is likely that leaks will be opened, due to the removal of the old scale, and not on account of any action the softened water has upon the metals entering into the construction of the boiler. Approved soft-metal gaskets should be used around all manholes and handhole joints, for no scale deposit will form at these points to seal small leaks left in replacing covers.

The best time to blow down boilers is after they have remained idle or have been operated for a time under low load, since in either case the solid matter in suspension will have had a chance to settle to the bottom or in the mud drums. The blow-off valves should be opened and closed slowly to avoid violent shocks. They should, however, be opened wide to permit the removal of scale fragments that may have lodged within the pipes or near the valve seats. Blow-off pipes should be carried outside the boiler room, with the end left exposed, that any leaky valve may be readily detected. Experience must govern the frequency of blowing down and the amount of water which must be blown off each time, for,

in addition to removing solid matter, blowing down is the only means of keeping the concentration of the highly soluble salts within the limits necessary to prevent foaming. Whenever boilers are cut out of service for cleaning or inspection, they should be filled with hot soft water, but care must be taken not to fill them so rapidly that it will temporarily place an overload on the water softener and impair the results. It is a good practice to open boilers every three or four months for inspection and washing, as a check on the attention given to the water softener.

Conversion of Soda Ash to Caustic Soda within Steam Boilers.— When water from a lime-soda or zeolite system is fed to a boiler, or soda ash introduced, as by boiler compounds or internal treatment, the soda ash is partially broken down to caustic soda.

$$Na_2CO_3 + H_2O = 2NaOH + CO_2$$

C. E. Joos gives, below, the result of operating a boiler in the drum of which 50 lb. of soda ash was placed before firing up. As the boiler is put under pressure the soda ash disintegrates and it completes its maximum conversion after the boiler has been in operation about two hours.

Fig. 2 illustrates the amount of conversion of soda ash to caustic soda that takes place in boilers operating under 282 lb. pressure, the data being taken at a jet condenser plant where almost 100% makeup was softened through a hot process.

For concentrated boiler waters, the phenolphthalein (Ph.) reading (p. 724) will indicate all of the caustic soda alkalinity plus one-half of the soda ash alkalinity, while the methyl orange (M.O.) reading will indicate the sum of the soda ash and caustic soda alkalinities. Subtracting the Ph. from the M.O. and multiplying by two gives the soda ash alkalinity. If 100 ml. water was used initially for testing, with twentieth normal acid, the soda ash alkalinity should be multiplied by 15 to give the amount of soda ash in gr. per gal. If the calculated soda ash alkalinity be subtracted from the M.O. reading and the result multiplied by 1.13, the result is caustic soda in gr. per gal., as in the following:

Ml. 1/20 Normal acid, 100 ml. sample, M.O. = 30.0, Ph. = 25.0
   (30.0 — 25 0) × 2 = 10 = soda ash alkalinity.
   (30.0 — 10.0) = 20 = caustic soda alkalinity.
   10 × 1 5 = 15 gr. per gal soda ash.
   20× 1 13 = 22 6 gr per gal. caustic soda.
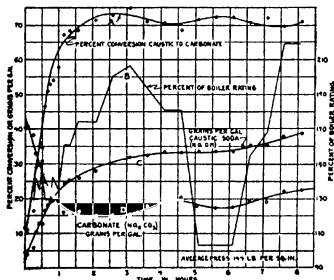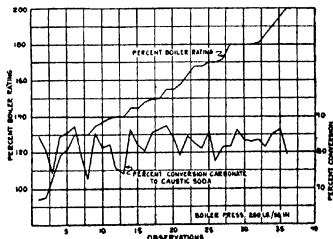
FIG. 1   FIG. 2

CONVERSION OF SODA ASH TO CAUSTIC SODA ASH IN BOILERS.

Priming and Foaming of Boilers.—Under severe priming conditions steam may carry more than 50% of moisture by weight, which, however, represents less than 1% by volume   Where priming breaks cylinder heads or otherwise wrecks engines higher percentages are undoubtedly present.

A. F. Joseph and *J. S. Hancock* report tests on dissolved salts as the cause of priming in an experimental boiler operated at 150 to 155 lb. pressure, evaporating 12 gal. per hr. per sq. ft. of water surface, with the water level 3½ in. below the steam valve. The table below shows the effects of various concentrations of pure salts, also of the impurities in a natural water containing initially 120 gr. per gal. of total hardness in terms of calcium carbonate.

Concentration ppm.	Per cent of priming when the salt used was:				Priming of a well water
	NaCl	*Na₂SO₄*	*Na₂CO₃*	*CaCl₂*	
	$NaCl$	Na_2SO_4	Na_2CO_3	$CaCl_2$	
1000	0	0	0	0	0
1500	0	0	0	1	0
2000	0	6	4	4	3
2500	2	14	9	7	12
3000	9	18	14	10	16
3500	13	20	17	12	18
4000	18	22	19	14	20

This does not support the idea that sodium carbonate is an especially objectionable constituent.

When operating at 125 lb. pressure, with a concentration of salts of 3500 parts per million, the effect of rate of evaporation was found to be as follows:

RATE OF EVAPORATION Gal. per Hr. per Sq. Ft. Water Surface	PERCENTAGE OF PRIMING		
	Sodium Chloride	Sodium Sulphate	Sodium Carbonate
9	7	7	9
11	16	22	16
13	25	33	24

The effect of pressure was as follows:

Pressure. Lb per Sq. In.	PERCENTAGE OF PRIMING		
	Sodium Chloride	Sodium Sulphate	Sodium Carbonate
70	45†	about 75†	about 80†
100	26	32	40
125	17	21	25
155	13	18	17

† Results extrapolated from the priming curves. These figures are certainly not too low.

Concentration of salts maintained at 3,500 p p.m. Rate of evaporation, 11 gals. per hr. per sq. ft. of water surface.

With the concentration at 3500 ppm., pressure 105 lb. gage, and rate of evaporation 15 gal. per sq. ft. per hr , there was 95% priming at the normal water level, which was reduced to 60% by lowering the water level 1 in. and to zero by lowering it 2 in. The general conclusions were:

(a) Priming in a boiler is caused by the layer of bubbles on the water surface increasing in thickness and stability to such an extent that it reaches the steam exit pipe so that water is ejected with the steam. It is accompanied by a rise in water level, which increases the effect.

(b) This may be brought about by a *high rate of evaporation,* a *low pressure,* or a *high water level.*

(c) In the case of any of the above, the effect is greatly increased by a high concentration of dissolved solids.

(d) Sodium carbonate has no greater effect in producing priming than other salts.

(e) The effect on priming of finely divided calcium carbonate or boiler scale is negligible.

(f) There appears to be no important difference as regards priming between hard and soft water.

(g) Castor oil exerts a very powerful effect in suppressing priming, and enables a water of high concentration of dissolved solids to be used in a boiler.

C. E. Joos defines foaming as a surface condition of water within a steaming unit, in which the steam space becomes filled, or partly filled, with bubbles or foam, due to a soapy or high alkaline condition of the concentrated water. Steam produced under this circumstance contains moisture, the amount depending on the nature and quantity of foam within the steam drums. Naturally, such a condition is not indicated by the surging of water in the gage glass as commonly occurs in severe cases of *priming*. Priming, on the other hand, is violent ebullition and usually indicates its presence by turbulent action, and intermittent slugs of water passing over with the steam into the lines. Of the two, priming is the more common, in that operating conditions affect its intensity, although some detrimental conditions can exist as a result of foaming.

A series of tests were made in an industrial plant using a hot process continuous lime-soda-ash softener. In one, a boiler was taken from 215% rating to 60% and then back to 226%, all in a period of ten minutes, resulting in calorimeter moisture readings well over 5%, which is as much as the calorimeter will indicate. Then the rating was gradually raised by cutting out units and subsequently increasing the load on the active boilers, carrying the water level steady and low, while the concentration of total solids was 79 gr., well below the normal operating figure of over 200 gr. The results are shown in Figure 1, the observations being taken at half-hour intervals. Priming was reflected by the amount of water discharged into a series of traps draining various headers along the boiler room, which were collected and examined for their content of alkaline soda and sodium chloride, calculated in terms of percentage of boiler water concentration. Thus, a trap discharge free of soda and salt would mean 100% dry steam, while those containing these materials indicate contamination of the steam proportionate to the percentage of boiler water contained in the trap discharges.
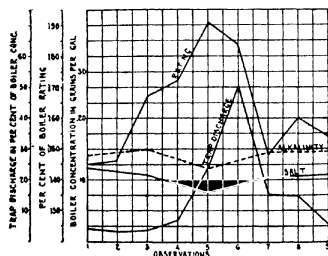
FIG. 1.—EFFECT OF HIGH RATING
ON STEAM QUALITY
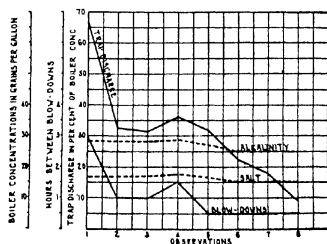
FIG. 2.—EFFECT OF FREQUENCY
OF BLOW-DOWN—*Power Plant Engg.*

During priming, the concentration of the boiler water was lowered, which is shown by the lower alkalinity and salt reading, the effect being much the same as that of blowing down a boiler   To get the factor of concentration low enough, it was necessary to blow down these boilers every hour during the night and every half hour during the day

Perhaps the most important factor governing priming conditions is that of the total dissolved solids present within the boiler water   This is logical in that these solids increase both the density and viscosity   Figure 2 shows the effect of relieving the boiler of the highly concentrated water by blowing down.   Starting with a schedule of blowing down every three hours and gradually increasing the blows to every half hour, the contamination of boiler water in condensed steam was reduced from 66 6% to 9 1%

With low concentrations in the boiler, it was found possible to keep the moisture in the steam under 1%, even when the boiler rating was increased from 128% to 188%

Experiments were also made on chemically precipitating sodium sulphate, the principal impurity in the boiler water, by barium hydrate, according to the reaction

$$Ba(OH)_2 + Na_2SO_4 = BaSO_4 + 2NaOH$$
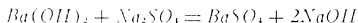
Barium sulphate is precipitated as a sludge in the softener and removed by the filter   By this treatment, when using a maximum of 6 lb. barium hydrate per 10,000 gal water, the sodium sulphate was reduced from 125 to 13 2 gr , and the total solids from 215 to 122 gr , but the treatment was too expensive.

Joos states that water-tube boilers having tubes arranged vertically are most susceptible to priming, particularly the two-drum design.   These boilers are used as waste heat boilers to a great extent and where the load is steady and the feed water good, no trouble is experienced, but priming may be experienced when they are forced   The horizontal-cross-drum, inclined-tube, sectional-header boiler is the type least susceptible to priming, with the longitudinal-drum, sectional-header type next in order, followed by the four-drum inclined bent-tube type and the longitudinal horizontal-drum, straight-tube, solid-header type, as used in the investigation here described. The longitudinal-drum, sectional-header type is better adapted to higher concentrations and erratic operating conditions.

The first important factor in the prevention of priming is careful control of the boiler concentrations.   In the tests described, with concentrations of approximately 60 gr , a rating of over 200% could be carried quite easily, while at 100% rating, a concentration of total solids of over 280 gr. could be carried without experiencing wet steam.   While there is a feeling among operators that blowing down a boiler beyond a fixed schedule is expensive, even under priming conditions, it must be remembered that a priming boiler is in effect blowing itself down through the steam outlet, and that neglect of blowdown may result in expensive repairs and shutdowns.   In the case investigated it was found that blowing down cost $9 00, while sufficient barium hydrate to give the same effect would cost $14 00 per day, and might possibly contribute to caustic embrittlement.

C. W. Foulk presents a theory covering the formation of masses of bubbles or froth on the surface of the water in boilers.   He states that the fundamental conditions of foaming are the presence of substances which concentrate either at the surface or in the mass of the water and thus either increase or decrease the surface tension, and of substances

which by imparting viscosity to the films will stabilize them and prevent them from bursting immediately after forming. In the average boiler water, the change of the surface tension is brought about by dissolved sodium salts, and the stabilization of the foam by finely divided solid matter, neither alone being sufficient to cause foaming. To test this theory, solutions of the chloride, sulphate, hydroxide, carbonate and bicarbonate of sodium and various mixtures, in concentration from 25 parts per million up almost to saturation, were boiled in pressure and vacuum flasks, with little or no evidence of foaming. In the stronger solutions the surface would be covered with large "goggle-eye" bubbles, which had only a momentary existence, and there was also momentary violent ebullition on adding solids. Various insoluble powders, such as pumice, sulphur, pyrolusite, bone black, lead sulphide, boiler scale, precipitated calcium carbonate and limestone, were also boiled in distilled water, with no appreciable foaming except in one or two cases with large quantities of solid, especially with limestone, which may have been slightly soluble. When present in sufficient concentration, any one of the sodium salts, together with any one of the insoluble materials mentioned, produced a white froth or foam of a certain degree of permanence, and in extreme cases several inches thick. A smaller concentration of the sulphate was required for the production of foam than of the other sodium salts, but the difference was slight. Among the solids, powdered boiler scale and limestone were most effective as foam producers. The foam-producing tendency of powdered boiler scale increased, for equal weights, as the size of particle decreased. However, scale all of which passed 40-mesh sieve produced foam. Tests with calcium chloride, potassium chloride, hydrochloric acid, acetic acid, potassium dichromate, sugar, ethyl alcohol and acetone as the soluble substances all gave foaming mixtures, with scale or limestone as the solids, but no foaming in water alone.

A fair amount of foam was obtained with concentrations of 1000 p.p.m. of sodium salts if the amount of insoluble material was sufficient, the foaming increasing till the sodium salts reached 7000 p.p.m. Foams were produced with low soluble material and high insoluble, and vice versa, but with less than 500 p.p.m. (30 grains per gal) of soluble salts, no reasonable amount of insoluble material would produce foam, and with less than 500 p.p.m. of insoluble matter, no concentration of soluble salts was sufficient to cause foam. Changes from 0.3 to 3.5 atmospheres pressure had no effect, except that at the higher pressures the bubbles were smaller and more nearly uniform in size, and a temporary violent ebullition accompanied by momentary increases in foam was noticed if, during the boiling, the pressure was suddenly reduced. A mere trace of castor oil stopped almost instantly the foaming of all the mixtures of soluble material, the films of which had been stabilized with finely divided solids, regardless of whether the dissolved substances had raised or lowered the surface tension of the liquid.

The Locomotive suggests that the obvious way to prevent foaming is by keeping, as far as possible, all impurities out of the boiler, whether soluble or insoluble, with periodical blowing down. If foaming does occur, check the drafts and cover the fires with fresh coal, or shut off oil or gas burners. Then shut the stop valve long enough to find the true level of the water. If this is sufficiently high, blow down some of the water in the boiler and feed in fresh water, repeating several times when

necessary. If the foaming does not stop, it is best to cool off the boiler, empty it, and seek further for the cause. After foaming has occurred, the gage glass and pressure gage connections and safety valve should be tested to make sure that they are clear. *L. J. Reed* states that the best time for blowing down is in the morning before unbanking the fires, or, in the case of boilers operating continuously, at some period of least steam demand, as, for instance, immediately after cleaning fires. Under such conditions the sludge has had a chance to settle, and a much greater proportion can be gotten rid of in one blowing. In general it is recommended that every boiler be blown down at least once every twenty-four hours sufficiently to flush out the blow-out pipes, with the valve opened wide if only for a few moments, but not opened or closed rapidly. Care must be taken to prevent uncovering tubes or portions of drums exposed to hot gases, by stationing an attendant at the gage glass to give warning of low water. Where only one man is on duty in the boiler room, it is well to make some provision for subduing the fire before blowing down, as it may not be possible to close a clogged valve. The best practice is to have two valves on the blow-off line and to blow down before unbanking. Low water has been caused by opening the valve on the wrong boiler. When two or more boilers are connected to the same blow-off pipe, if any of the boilers are empty the valves to them should be locked to prevent steam blowing back into such boilers. When the discharge is into the open, special precautions should be taken to prevent the scalding of persons near the outlet. Where surface blow-offs are provided, these may be opened frequently, but only for a few moments at a time.

Effect of Oil in Producing Foaming.—Oily condensate, if used for boiler feeding, is frequently the cause of serious operating troubles, including:

1. Foaming and priming.
2. Overheating of boiler plates.
3. Corrosion.

Compounded oils are more likely to give rise to foaming and priming than are straight mineral oils, especially if the water fed to the boilers has been treated to prevent scale, since the fats added in compounding the oil saponify with the soda present in treated water to form soap. If the water is not treated with soda, corrosion is apt to result from the use of compounded oils, as the material used for compounding, such as tallow, may break up into organic acids.

That oil contamination may cause priming and foaming is indicated by the following analysis of a deposit from the steam space of a boiler:

	Per Cent
Oil	20 0
Silica	4.0
Iron oxide	8.2
Calcium carbonate	62.8
Magnesium carbonate	4 4
	99.4

This deposit covered the entire steam space, showing that severe priming and foaming must have taken place. That the oil present was one of the causes of the priming or foaming may also be inferred.

A—STEAM PASSAGES OF STEAM TURBINE CHOKED WITH GREASE
AND SLUDGE

Oil is carried over with sludge in the boiler water into the turbines and, becoming cooler as a result of the steam doing work, congeals and acts as a binder for other substances brought over by priming. The analysis given below is representative of such a deposit

			Per Cent
Oil	. ...	.	. 24 88
Silica .	. . . ..	. .	.. 13.80
Iron and alumina		.. ...	. 6.19
Calcium sulphate	.		. 0 03
Calcium carbonate	.	.	. 55.10
			100.00

If superheaters are used, it is only a question of time when their efficiency will be impaired and when they will become plugged or burnt as a result of oil deposits.

Fig. A illustrates what happens to turbine passages where there is oil contamination and priming

Oil in condensate exists in two different forms, free oil and emulsion. Free oil will float to the surface if the condensate is allowed to stand for a short time This oil can be separated from the condensate by the ordinary gravity methods, skimming the oil from the top and taking the clear condensate from below the surface, or it can be removed more or less effectively by suitable cloth filters, grease extractors, etc

In the emulsified form, the oil is divided up into such fine particles that they remain in a state of suspension, and no amount of settling will separate the oil. The oily particles, which can be seen with a microscope, vary in size, but some of the globules are only 0.00001 in. in diameter. Oil in this state passes through ordinary blotting paper or filter paper, and ordinary mechanical means of filtration are not effective. Efficient means for removing emulsified oil will be discussed subsequently.

The presence of either free or emulsified oil in condensate can usually be detected by the naked eye. Minute quantities can be detected by dropping a strip of camphor into the sample. If oil is present, the camphor will move about sluggishly, while in the absence of oil it will dart about rapidly, as may be observed for comparison by dropping a similar piece of camphor into pure water.

Estimation of the quantity of emulsified oil is easily made by shaking a known quantity of the sample with a small quantity of a solvent, such as ether or chloroform. On settling, the oil will be dissolved in the solvent, while the water will be perfectly clear and oil free. Separation of the water and solvent is then made by drawing off the clear water and evaporating the solvent and weighing the oily residue.

As prevention is generally better than cure, the use of oil separators for the separation of entrained oil from exhaust steam before the latter is condensed is generally to be recommended. If the separator is properly installed and a suitable grade of oil is used, the oil will be removed so effectively that the condensate can be used for cooking, dyeing, washing, ice manufacture, or boiler feeding, without further treatment.

Where there are so many exhaust lines that the installation of oil separators would be expensive, or where the exhaust steam system is already badly fouled with oil, it may be preferable to remove the oil from the exhaust steam after the latter has reached the liquid form. If the oil is in the free state, separation can easily be accomplished by the installation of a tank, taking the clear condensate from below the surface and skimming the oil from the top. If in the emulsified form, the oil particles must be brought together by coagulation.

The fine substance used as the coagulating agent should be such that it will form a precipitate of a voluminous and spongy nature, and which will have considerable absorbent power in bringing together the finely divided particles of oil. Coagulants recommended for the removal of oil from condensate are alum, aluminum sulphate or ferrous sulphate, commonly known as copperas. The chemical formulas are as follows:

Aluminum sulphate · $Al_2(SO_4)_3$ $18H_2O$.
Ammonium alum. $Al_2(SO_4)_3(NH_4)_2SO_4 \cdot 24H_2O$.
Potassium alum: $Al_2(SO_4)_3K_2SO_4 \cdot 24H_2O$.

The use of alum of either the potassium or the ammonium variety will result in increased concentration of soluble sulphates in the boiler water. This may not be of importance in many cases, but is of significance when the condensed returns form a large precentage of the boiler feed water.[*] Whether or not alum, aluminum sulphate or ferrous sulphate should be used depends, therefore, upon conditions. In small plants where there is only a small percentage of condensed returns, alum becomes the most convenient, inasmuch as it can be purchased in lump form, is easily handled and does not require so elaborate apparatus for feeding it as does aluminum sulphate. On the other hand, where the condensate returns form a greater percentage of the boiler feed water, aluminum sulphate or ferrous sulphate is applicable, as it does not increase the sulphate concentration to so great an extent, and more elaborate feeding devices are justified in view of the reduction of blow-downs and cost of chemical.

It is not to be inferred that the introduction of any amount of aluminum or ferrous sulphate of itself will coagulate the oil. Except for the oil, condensate is practically distilled water, and it is necessary to feed some alkaline substance, such as soda ash or caustic soda, to precipitate the alumi-

num sulphate, alum or ferrous sulphate, in order to form spongy, jelly-like particles. The precipitating agents may be fed to the condensate in a way similar to that in which the coagulating reagents are fed. The aluminum hydrate or ferrous hydrate particles entangle the microscopic oil globules in suspension, and, having brought these particles together, it is a matter of filtration to remove them, leaving crystal-clear condensate with a few grains of sodium sulphate, depending upon the amount of caustic soda or soda ash and coagulant used

In many cases where condensate is now discarded because of oil contamination, the installation of filtering equipment will result in savings that will pay for the apparatus in a short time. The present-day tendency toward higher boiler ratings and higher steam pressures makes it advisable to' utilize all the condensate available, as blowdowns and foaming and priming tendencies are thereby reduced

Mechanical Entrainment differs from priming and foaming in that it may occur with waters low in mineral solids. Entrainment of quantities of moisture in excess of 1 or 2% is most apt to occur in boilers operating at extremely high ratings. The entrainment of moisture will increase with the ratings, although not generally in the same proportion. Operating the boiler at extremely high rating may cause entrainment of moisture amounting to 2 to 5%. The effects of entrainment, while not so severe as those of priming, are sufficiently serious to call for the installation of steam purifiers

Results of Steam Contamination. With boilers operated at 200 to 400% rating, even under the best water conditions, as where surface condensers and evaporators are installed, the mechanical carry-over may be sufficient to reduce the superheat materially, and to cause deposits in the steam lines, superheaters and turbines. Even though evaporators are installed, solids find their way into the boiler through condenser leakage and from foaming and priming of evaporators. Although the solids entering with the feed may ordinarily be considered trifling and inconsequential, they may concentrate in the boiler to appreciable quantities. To illustrate, suppose a 1000-H.P. boiler is operated at 400% of rating and that the boiler water concentration is but 100 gr. per gal. Steam containing 2% of moisture from such a boiler would carry with it in a month's time approximately 208,000 gal. of concentrated water, containing 2975 lb. of solid matter. This moisture would probably be evaporated in the superheater, and the solids would be deposited there or would be carried along as a fine dust or powder. If slugs of water are carried along with the steam, the damage may be more pronounced than with constant entrainment. Where boiler water is treated, the boiler water alkalinities are made up chiefly of caustic soda, which readily attacks brass valves, dissolving out the zinc. The suspended matter usually carried over adds to the cutting effect of caustic soda by acting like a sand blast. Where valves are made of iron, this corrosion and erosion are not so noticeable as with brass valves, but they interfere with proper functioning, so that valves cannot be closed tightly.

The effect of steam contamination on turbine blading is illustrated by Fig. A (p. 764). The accumulation of dirt on turbine blades is usually not the only difficulty to be overcome, for moisture and dirt have a cutting effect, which may ruin the entire rotor of a turbine. *Roger W. Andrews* calls attention to the fact that a reduction of ½ of 1% in the efficiency of a turbine, due to wearing of buckets, which would be quite difficult to detect by test, will, for a turbine taking 150,000 lb. of steam per hr., require over 5,000,000 lb. of steam additional in a year of 300 days, representing a loss of over $2000.00.

Fig B shows a receiver type of steam purifier, installed between the boiler steam drum and the superheater inlet It has large storage capacity for the separated water, so that its effectiveness in stopping slugs of water is practically independent of the capacity of the trap which drains it Such a device used in connection with a 588 HP bent-tube boiler delivered practically dry steam at 50 to 250% boiler rating, when using treated water containing initially 20 gr. of total solids, the concentration of salts in the boiler running from 200 to 300 gr. per gal Trap discharges indicated that at times of severe priming the purifier was removing 40% of moisture from the steam, protecting superheater tubes and turbine blades from the sludge carried by this water. With 5-gr water, and 35-gr concentration of soda in the boiler, the steam samples showed no trace of soda alkalinity and only 0 18 to 0 26% of moisture by calorimeter tests, which is negligible from the standpoint of deposits and erosion
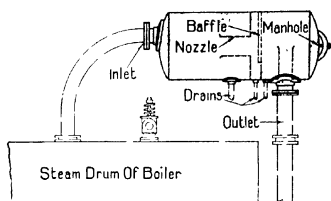
B RECEIVER TYPE OF PURIFIER INSTALLED BETWEEN OUTLET OF BOILER AND SUPERHEATER INLET

Steam Calorimetry.—The real test of success of a steam purifying device is the extent to which it gives protection from erosion and deposits, but it is often desirable for research purposes to estimate the moisture content of steam by a calorimeter. The throttling calorimeter depends on the superheating which occurs when steam at boiler pressure passes through an orifice to a lower pressure, usually atmospheric, and consists essentially of a discharge pipe with a thermometer before and one after the orifice. Fig. C shows a calorimeter connected to a standard A. S. M. E. sampling pipe, consisting of a ½-in pipe closed at the inner end and perforated with at least twenty ⅛-in holes drilled in spiral rows, the holes to be at least 1 in. from the wall of the steam pipe into which the sampling pipe is to be introduced. The sampling pipe should preferably be located in a vertical main not too near the boiler outlet nozzle Sampling pipes should not be located at the ends of bends, where centrifugal action may have separated the moisture and thrown it to one side, thereby depriving the sampling pipe of a representative sample.
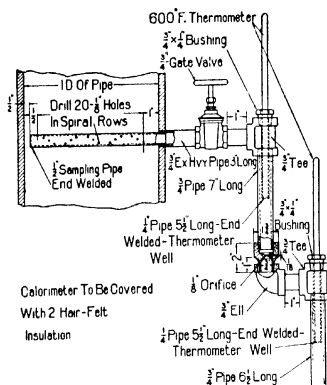
C. — THROTTLING CALORIMETER WITH SAMPLING PIPE
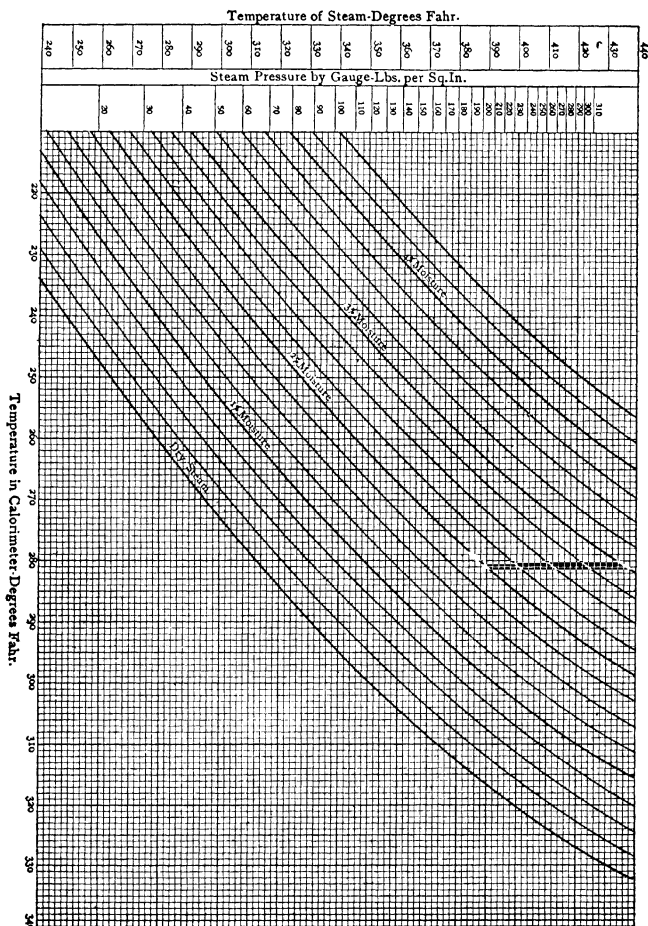
D.—INTERPRETATION OF CALORIMETER READINGS
—"Steam" (B. & W. Co.)

Since no mechanical work is done in the calorimeter, the total heat is, except for radiation, the same on both sides of the orifice. For a calorimeter exhausting to atmosphere,

$x = [H - 1150\,4 - 0\,47\ (t - 212)] \div L$, where

x = proportion by weight of moisture in steam
H = total heat of steam at the higher pressure, BTU per lb.
t = temperature of steam after passing orifice, °F.
L = latent heat of steam at the higher pressure, BTU per lb.

Fig. D, for steam initially saturated, enables one to read the % moisture directly from the temperature in the calorimeter and the temperature of the steam tested. To eliminate errors due to radiation, stem correction of thermometers, etc., the "normal correction" of the calorimeter is determined when operating the boiler with fresh water, at 50% rating, so as to produce 100% dry steam. The difference of the average reading of the second thermometer from the theoretical temperature to be expected is the normal correction, which should be added to the temperature readings when making tests, before calculating the % moisture. The calorimeter shown in Fig. C had a normal correction of only 3° F. The capacity of throttling calorimeters depends on the heat available for superheating the steam; with steam at 50 lb., they will not indicate over 3.05%, regardless of the total moisture present; at 150 lb. not over 5.2%, and at 250 lb. not over 6.33%. Also, as a throttling calorimeter is not an instrument of precision, results should not be relied upon beyond the limit of error. Even though the calorimeter be fairly accurate, an appreciable error may be introduced by the type and location of the sampling pipe, not to mention uneven distribution of the moisture in the steam.

Embrittlement of Boiler Plate.—Caustic embrittlement of boiler plates causes the steel to lose its elasticity, and, when embrittlement is well advanced, to become as fragile as cast iron. The blow-off flanges may in some cases be cracked by a firm blow with an 8-lb. hammer, and rivet heads sometimes pop off when it is attempted to caulk joints.

S. W. Parr and *F. G. Straub* present the following conclusions:

1. Embrittlement cracks are easily distinguishable from corrosion cracks and fatigue cracks.

2. Embrittlement cracks result from a combination of strain of the metal beyond the yield point and a large ratio of sodium hydrate to sodium sulphate or sodium carbonate.

3. Where embrittlement occurs in approved boiler construction the probability is that some of the metal surrounding the rivets has been strained beyond the yield point.

4. To produce embrittlement of steel subjected to excessive strain in the laboratory a concentration in excess of 300 grams per litre (17,500 gr per gal) of sodium hydrate was necessary This concentration is probably 100 times greater than is ever found in modern boilers and more than 300 times what is regarded as good practice for modern boiler operation.

5. This excessive concentration may result from slight leakage between the riveted seams, with evaporation of the water.

6. The presence of twice as much sodium sulphate as caustic soda in the water prevents embrittlement. The protection given is probably due to the sodium sulphate being precipitated or thrown out of solution in the seams long before the caustic soda reaches a concentration that will do harm. The action of the sodium sulphate, therefore, appears to be of a mechanical nature, causing stoppage of pores and preventing the action of the caustic soda.

7. Natural waters having a low ratio of sodium sulphate to sodium carbonate (a good portion of the latter is changed to caustic soda in the boiler) are found in only comparatively few and restricted areas in the United States.

8 A low ratio of sodium sulphate to sodium carbonate frequently results where water is treated by the zeolite softener, which transforms the calcium and magnesium carbonates to sodium carbonate, commonly giving a ratio of sodium sulphate to sodium carbonate less than 2 to 1. This relationship may also result from treating water with soda ash if the sulphates are unusually low, and particularly if sodium carbonate is fed in greater excess than required

9. If treatment of water in a zeolite softener or by chemicals gives a ratio of sodium sulphate to sodium carbonate less than 2 to 1, supplementary treatment should be given to bring the ratio up to approximately 2 to 1.

10. The most practical treatment for natural waters high in sodium carbonate and low in sodium sulphate, or for zeolite treated waters which after treatment have a large amount of sodium carbonate with respect to sodium sulphate, is with sulphuric acid. The boiler feed water at the University of Illinois, which is naturally high in sodium carbonate with respect to sodium sulphate, is treated with sulphuric acid, as are also waters treated by zeolite softeners where required.

Parr gives below water analyses typical of the district near the University of Illinois. Their characteristics are absence of permanent hardness, relatively small amounts of sulphates of sodium and potassium and the presence of natural sodium carbonate alkalinity.

With the exception of Bloomington, all of the analyses show at least twelve times as much sodium carbonate as sodium sulphate and Bloomington has more than twice as much sodium carbonate as sodium sulphate. Corrective measures proposed were treatment with magnesium sulphate or sulphuric acid, either of which will lower the sodium carbonate alkalinity and increase the sodium sulphate.

ALKALINE WATERS IN THE URBANA-CHAMPAIGN DISTRICT
DISSOLVED SOLIDS IN GRAINS PER UNITED STATES GALLON

Location	Urbana	Hoopes-ton	Paxton	Normal	Bloom-ington	Bement	Tolono
Depth of Well (in Ft.)	160	350	120	180	174	150	146
Supply	U. of I.	City	City	City	Big 4	City	City
Potassium Carbonate. ...	09						
Potassium Nitrate	05					.04	
Potassium Chloride ...	24	.12		89		1.78	.32
Potassium Sulphate ..	18	08					
Sodium Nitrate			.07		.02		
Sodium Chloride			.26	.16	.77	1.98	.33
Sodium Sulphate			.39	.18	3.60	.37	.27
Sodium Carbonate .	5 09	3 96	6.56	12 06	8.15	4.53	12.61
Ammonium Carbonate	.71	.09		60		.32	1.59
Magnesium Carbonate.	6 40	5 95	6.98	4 70	9 01	7.63	7.33
Calcium Carbonate ...	8 40	7 60	10.71	7.30	13.07	9.02	12.93
Iron Carbonate	21	19		.12	.01	.26	.22
Alumina	.05	.14		05		.01	.23
Silica	1.47	81	1.30	.81		.79	1.34
Bases	.00	.01		.15		.11	.06
Undetermined					1 57		
TOTAL	22.80	19 04	26 27	27 02	36 20	26 82	37.23

Parr attributed embrittlement to nascent hydrogen liberated as indicated in the following equation:

$$3Fe + 4OH = Fe_3O_4 + 4H$$
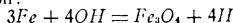
The effect of the nascent hydrogen is likened to the pickling action of dilute acids, which causes temporary embrittlement of steel. The action of sodium hydrate at the higher boiler temperature he believed to be somewhat similar.

Laboratory tests demonstrated that embrittlement could be developed in steel stressed in contact with strong caustic solutions. The strength of sodium hydrate solution required to cause embrittlement was such as might be assumed to be developed between the seams if slight leakage were

permitted; *i. e.,* if the seams were not caulked on the inside to prevent slight leakage and concentration.

R. S. Williams and *V. O. Homerberg* advance the theory that in the original crystallization of the steel the slag impurities are rejected to surfaces of the grains. These impurities are chiefly oxides and sulphides of iron, which are reduced by nascent hydrogen to form water and hydrogen sulphide. The formation of water and hydrogen sulphide is believed to produce excessive strain between the crystals, causing the intercrystalline cracks characteristic of embrittlement. Their experiments also showed that stresses in the steel played an important part in producing this embrittlement. Their preliminary report offers no explanation of the part that sodium sulphate plays in preventing embrittlement.

An association of German boiler manufacturers recommends more rigid inspection of plate and better boiler construction, including better regulation of air pressures in boiler riveting It was especially emphasized that riveting pressures be not so high as to cause an indentation below the rivet head. It was claimed that with properly fitted plates the high pressures frequently used for riveting were not required.

The theory has also been advanced that the cause of embrittlement of boiler plate is a combination of dissolved oxygen and operating strains. If oxygen alone is present and the boilers are not submitted to excessive strains at riveted seams, corrosion or pitting is observed, whereas if the oxygen is accompanied with excessive strain, embrittlement results. In substantiation of this theory it is pointed out that wherever these intercrystalline cracks are found iron oxide appears on the surface of the metal between the cracks. This oxide, it is claimed, can only be formed where there is oxygen in the water. On the basis of this theory, the fact that embrittlement is localized in plants where the water is naturally high in sodium carbonate is attributed to the metal of such boilers not being protected against attack by oxygen. This theory would argue for the deaeration of water from zeolite softeners, which is commonly high in sodium carbonate, as well as such natural water supplies as come within this classification.

The fact that embrittlement of boiler plate has been localized or found in restricted areas where the water has similar characteristics, namely, small amounts of sodium sulphate and relatively large amounts of sodium carbonate, indicates that this is a relationship that should be avoided. The universal use of soda ash, either as the basis of boiler compounds for internal treatment or in connection with properly designed water softening equipment, shows that sodium carbonate of itself cannot be a cause of embrittlement. A relatively small ratio of sodium sulphate with respect to the sodium carbonate appears to be a more logical cause

On the other hand, the fact that many boilers have been operating for years without developing embrittlement with sodium sulphate very low in respect to sodium carbonate and with water having characteristics similar to those where embrittlement of boilers has been observed indicates that boiler construction or the quality of the plate may have something to do with embrittlement.

If embrittlement be attributed solely to the characteristics of the boiler feed water it would seem that boilers caulked on the inside or so designed as not to permit leakage between the seams would not suffer from embrittlement, regardless of the character of the water supply, since embrittlement would not result from any degree of alkalinity that could be maintained in the boiler, regardless of the amount of sodium sulphate present.

In view of what has been observed, as briefly outlined above, the purchasers of boilers and water purifying equipment would do well to insist upon inside caulking of boilers and treatment of the water to maintain as high as possible the ratio of sodium sulphate to sodium carbonate. If the initial character of the water is such that any practical treatment which might be given the water to prevent scale and corrosion would give a low ratio of sodium sulphate to sodium carbonate, it can be corrected by feeding sulphuric acid, calcium sulphate, magnesium sulphate, sodium sulphate or other sulphate. As all sodium salts tend to increase the priming of the boiler, it is always desirable to use such treatment as will keep the total sodium salts as low as possible The proper solution of this problem will probably be found to depend upon boiler construction and the character of the water.

Zeolite softeners have been used in many comparatively small boiler plants, as in laundries or other industries, where they are installed primarily for treatment of process water. Waters treated by zeolite softeners frequently have sodium carbonate considerably in excess of sodium sulphate, but embrittlement where zeolite softeners are used is comparatively rare. This would indicate that the small boiler plant, which is commonly hand fired and operated at lower pressure and temperatures than modern boilers designed for higher pressures and high ratings accompanied by higher furnace temperatures, is less subject to embrittlement, regardless of the ratio of sodium carbonate to sodium sulphate.

The research work which has been done on this subject also indicates that high temperatures and high pressures are more likely to be associated with embrittlement than are lower temperatures and pressures, all other conditions remaining the same.

Recognizing the seriousness of embrittlement of boiler plate and also the fact that exact causes and preventives are not as yet definitely known, the *Boiler Code Committee* of the *American Society of Mechanical Engineers* has suggested the following for the guidance of operators of steam boilers and other pressure vessels in service.

CA-5. Cracks in riveted joints are generally attributable to steel of unsuitable quality, to excessive internal stresses in the plates caused by high riveting pressure, imperfect thermal or mechanical treatment during fabrication, unskillful or abusive treatment during the repair of leaky seams, also to extremely severe operating conditions. Cracks from such causes occur in riveted joints, both above and below the water level in boilers

The attention of the committee has been called to the following exceptional cases in rivet-joint cracks, described as intercrystalline in character and under the water level only: (a) boilers in certain localities fed with well water containing sodium bicarbonate, but not an appreciable amount of sodium sulphate (similar cracking has not been reported in the same localities in boilers fed with surface water free from sodium carbonate or containing sodium sulphate equal to or exceeding the sodium bicarbonate); (b) boilers fed with water in part composed of condensate from leaky caustic evaporators; (c) boilers fed with sea water distillate to which compounds were added, resulting in high concentrations of sodium alkalinity.

In view of the particular cases of embrittlement cited above and pending further research, the maintenance of not less than the following ratios of sodium sulphate to the soda (methyl orange) alkalinity is recommended as a precautionary measure.

Working Pressure of Boiler Lb Gage	Relation of Sodium Carbonate Alkalinity	to	Sodium Sulphate
0 to 150..............	1	to	1
150 to 250..............	1	to	2
250 and over...........	1	to	3

Cracks of this particular character have not been reported in cases where water softening equipment has been intelligently used, with close control over boiler concentrations, and the boilers properly operated

Pending further operating data from boilers in service, it is recommended that the requirements of Par. 1-44 of Section VI of the Code be extended to all riveted seams and that careful examination of all seams be made if leaks occur and do not remain tight after caulking

CA-6 When the carbonate hardness in a water exceeds the permanent hardness by more than 3 gr per gal (51 p p m) or when sodium bicarbonate is present in excess of 3 gr per gal (51 p p m), then treatment should be made to remove free carbon dioxide and to reduce the carbonates before using soda or other reagents for removal of permanent hardness

CORROSION

Corrosion of boilers is apt to result from one of three causes:

1. Corrosion due to acid, free or generated.
2. Electrolysis.
3. Gaseous corrosion from gases such as carbon dioxide and oxygen.

Free acids may occur in water supplies from thickly populated industrial districts, as around Pittsburgh, receiving drainage from steel mills and mines. It is common practice to use lime to neutralize such acids, although lime will form calcium sulphate with free sulphuric acid and cause deposition of considerable amounts of scale   Better practice would be to neutralize the free acid with caustic soda or preferably soda ash. Caustic soda or soda ash would form sodium sulphate and afford greater protection against the formation of scale.

Acid corrosion due to *generated acids* may be caused by the breaking up of salts, such as magnesium chloride, into hydrochloric acid and magnesium hydrate, when subjected to boiler pressures and temperatures; the reaction being as follows

$$MgCl_2 + H_2O \rightarrow MgO + 2HCl$$

R. E. Hall takes exception to this explanation, stating that the corrosion of iron due to magnesium chloride follows along these lines

$$Fe + 2H_2O \rightleftarrows Fe(OH)_2 + H_2$$

$$Fe(OH)_2 + MgCl_2 \rightleftarrows FeCl_2 + Mg(OH)_2$$

Hall further states that if the value of $Mg++$ exceeds 220 p.p m , the precipitation of $Mg(OH)_2$ will occur and the concentration of dissolved ferrous iron in the solution will increase until equilibrium is established for the magnesium concentration of any solution in contact with the metal. On the other hand, if the concentration of $Mg++$ is less than 220 p.p.m. the corrosion of the metal should, in the absence of oxygen, proceed only to the saturation value of ferrous hydroxide, just as in other salt solutions.

Ordinarily this type of corrosion occurs most generally in plants using sea water for condensing service, in which case there is some leakage through the condenser, giving the salt water access to the boilers. The maintenance of the proper alkalinity through the introduction of soda ash or caustic soda serves to precipitate the magnesium salts as hydroxide and thereby eliminate the corrosion.

The corrosion of boilers may be brought about by electrolysis, although this type of corrosion is rather rare. Cases have been reported, however, where water has been grounded to some point of central station electrical equipment carrying a positive charge. To determine whether corrosion is

due to electrolysis, galvanometer readings can be taken at different points in the boiler, as at the blowoff line, steam nozzles and drum, and the various potential drops calculated.

Corrosion by Gases.—The part played by dissolved air in causing corrosion has come to be understood only in recent years. *W. H. Walker*, of the Massachusetts Institute of Technology, says: "Engineering magazines continue to publish lengthy articles upon the pitting of boiler tubes, the rusting of water supply systems, the red water plague, anti-corrosion compounds, and the like These papers describe the symptoms, and generally prescribe a cure, but say never a word as to the cause of the trouble. . . He (the engineer) continues to drug his boiler or physic his hot water supply system, in a vain attempt to cure the disease, but takes no steps to prevent it. Corrosion is an electrolytic phenomenon, and can be understood by electrical engineers on purely electrochemical grounds. It takes place at ordinary temperatures only in the presence of water, through the reaction $Fe + 2H^+ \longrightarrow Fe^{++} + 2H$. This means that a metallic iron atom, electrically neutral, impacts with two hydrogen ions present in the water, and which carry electrical charges. The result is the production of an iron ion which takes up the electrical charges from the two hydrogen ions, and the deposition of two atoms of hydrogen. . . . The retarding action of the hydrogen film, which is stable in the absence of oxygen and any acid-forming compounds, is so controlling that from this point of view oxygen (or air) may be said to be the cause of corrosion. If oxygen be completely removed from the boiler feed water, the boilers will not pit nor corrode. If oxygen be separated from the feed of ordinary hot water supply lines, the red water plague and other corrosion troubles will disappear. . . The greater the concentration of hydrogen ions, the more rapid will be corrosive action, hence if any substance forming hydrogen, such as carbonic acid or bicarbonates, or sulphur dioxide, or any acid-forming compound, be present, corrosion is accelerated. On the other hand, if an alkaline material, such as soda ash, or caustic soda, be present, the number of hydrogen ions is decreased, and corrosion is retarded. If enough hydroxyl (the active ion of an alkaline compound) be present, practically all of the hydrogen will disappear and corrosion will entirely cease."

F. N. Speller says: "Corrosion is prompted and made progressive and continuous by the action of dissolved oxygen in water. When the supply of oxygen ceases, the reaction rapidly slows down, as all the available free oxygen is used in depolarizing the surface or in combining with ferrous hydrate. In the end the water is 'deactivated' in the sense that it has been rendered practically inert to metals. . . The degree of aeration of the water is the controlling factor in hot water supply lines, so that it is of the first importance, where iron pipe is used, to provide for the removal of as much as possible of the free oxygen and carbonic acid." He describes a system in which water for the heating circuit was 95% de-oxygenated in a storage tank filled with expanded steel lathing, and also states that water from an open heater at a temperature over 180° F. was used for ten years with practically no corrosion. The presence of free CO_2 in ordinary quantities apparently had no effect in causing corrosion. However, the ordinary chemical treatment of water for the removal of carbonates and sulphates of calcium and magnesium also disposes of the dissolved CO_2. The use of an open or direct contact feed water heater, where the water is

raised to steam temperature while in a finely divided condition, giving an opportunity for the liberated air to escape, is an effective, cheap and convenient method for deaerating water.

The rate at which water containing oxygen in solution will corrode the tubes of economizers and boilers and iron and steel pipes, as in hot-water heating and supply systems, is exhibited in Fig. 1, showing the quantity of iron converted into rust in a year by water containing different amounts of oxygen in solution and supplied at the rate of 1000 lb per hr.

R. E. Hall states that in *feed pipes* and *economizers*, the temperature is relatively low and the development of hydrogen is slower, but the oxygen content may be high, resulting in rapid corrosion with the removal of the hydrogen film by the higher oxygen concentration. The amount of sodium carbonate used for prevention of adherent-scale formation does not repress acidity sufficiently for the prevention of corrosion in this part of the plant, and the use of sufficient caustic to inhibit corrosion in the feed lines may be inadvisable on account of the additional caustic later formed in the boilers from the sodium carbonate in the treated water. The other remedy lies in the removal of oxygen, by making certain that the feed-water is heated to boiling temperature in a well-vented heater, or in the use of a deaerator. *Hall* says further that at *boiler* temperatures the extent of dissociation of water into hydrogen ions, H^+, and hydroxyl ions, OH^-, is greater than in cold water, favoring high hydrogen-ion concentration, and the rapid motion also interferes with the stability of the hydrogen film. However, the oxygen in the boiler water is exceedingly low, and the necessary excess of sodium carbonate to insure the absence of solid calcium sulphate crystals is much larger than in the entering feedwater because of concentration due to evaporation, while some of it is being decomposed to form caustic soda and CO_2. The hydroxyl developed in this manner maintains the hydrogen-ion concentration very low (product of the two is constant), and this minimizes the rate of solution of metal, so that chemical treatment of water for the purpose of scale prevention simultaneously functions in minimizing corrosion in boilers.

The manufacturers of steel and iron pipe and tubes generally agree that if the oxygen content of the water is maintained below 0.2 c.c. per liter, oxygen corrosion will be practically negligible, and certain makers of economizers are said to guarantee their tubes against corrosion provided the oxygen content of the water is maintained below 0.15 c.c. per liter.

The amounts of oxygen and nitrogen which can be dissolved in water under a pressure of the gas equal to 1 lb. per sq in. and at different temperatures are shown in Fig. 2. The solubility increases directly as the pressure of the gas. The pressure referred to is the partial pressure of the particular gas being considered. The normal atmosphere at sea level, for example, contains about 4 parts by volume of nitrogen and 1 part by volume of oxygen, and exerts a total pressure of not quite 15 lb. per sq. in. The partial pressure of each gas is the same fraction of the total pressure that its volume is of the whole volume. The partial pressure of oxygen in the atmosphere is therefore about 3 lb. per sq. in. Oxygen is somewhat more soluble than nitrogen, so that the mixture released from solution in water is usually richer in oxygen than is ordinary air. If the gaseous mixture
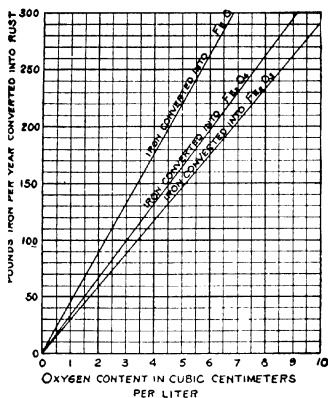
1, IRON CONVERTED TO RUST YEARLY
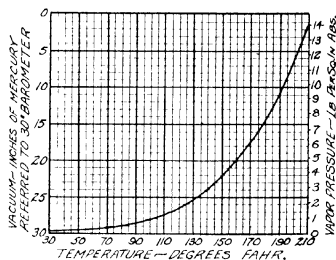
3 VAPOR PRESSURE AND VACUA CORRESPONDING TO DIFFERENT WATER TEMPERATURES
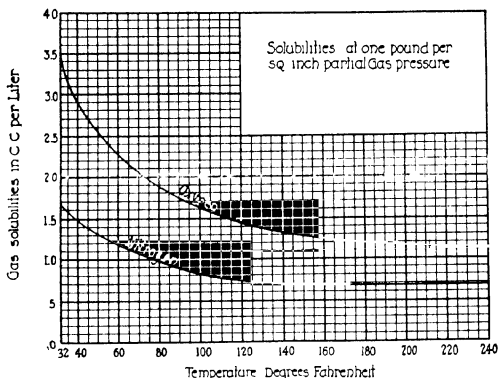
2 SOLUBILITY OF OXYGEN AND NITROGEN

contains water vapor, the partial pressure due to the latter, as given in Fig. 3, is to be subtracted from the total pressure in order to find the partial pressure of the gases. At boiling point, the water vapor pressure is equal to the total pressure and the partial pressure of oxygen or other gases is zero. No oxygen can therefore be dissolved in water at boiling point.

G. H. Gibson shows, in Fig. 4, the solubility of oxygen in water at various temperatures from atmospheric air at various total pressures.

SOLUBILITY OF OXYGEN
FROM AIR IN WATER
AT VARIOUS TEMPERATURES
AND TOTAL PRESSURES

TEMPERATURE—DEGREES FAHRENHEIT

4   SOLUBILITY OF OXYGEN
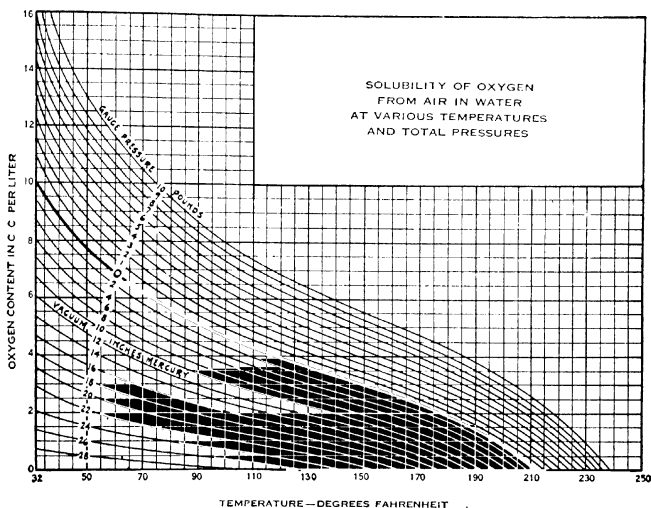
Determination of Dissolved Oxygen in Water. Method of *L. W. Winkler.*

APPARATUS REQUIRED

Manganese Chloride solution   40 grams $MnCl_2 4H_2O$ dissolved in water and diluted to 100 ml.

Sodium Hydroxide solution containing Potassium Iodide (KI) 31 grams $NaOH$ dissolved in water diluted to 100 ml. Add 10 grams KI to solution

$N/100$ Sodium Thiosulphate solution   When using a 200 ml sample 1 ml of the $Na_2S_2O_5 5H_2O$ will be equivalent approximately to 4 mg. or 0 28 ml. of O per liter
The actual factor is recorded on the label
Concentrated hydrochloric acid, commercial strength
Fresh starch solution made by placing ½ teaspoonful of soluble starch in 100 ml. water and bringing to boil
300 ml flask with 3-hole rubber stopper and rubber tubing sampling connections; reagent bottles, 25 ml burette, with stand and clamp, three 2 ml pipettes, porcelain casserole or a 600 ml beaker, 500 ml graduated cylinder.

To a 300 ml sample in sampling flask add 1 ml of Sodium Hydroxide and Potassium Iodide solution   Add 1 ml of Manganese Chloride solution
1. $2NaOH + MnCl_2 = Mn(OH)_2$ [white precipitate] $+ 2NaCl$.
   If Oxygen is present.
2. $Mn(OH)_2 + O = H_2MnO_3$ [manganous acid brown precipitate]   Add 5 ml. of concentrated hydrochloric acid   If no O is present solution will be colorless. It O is present solution will be yellow, or brown, according to the amount of O in original sample
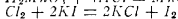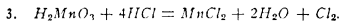
3. $H_2MnO_3 + 4HCl = MnCl_2 + 2H_2O + Cl_2.$
    $Cl_2 + 2KI = 2KCl + I_2$
    Up to this point the sample must be scrupulously protected from contact with the
    atmosphere   The yellow or brown color is due to the presence of free iodine (I)
    in the sample   Take 200 ml of the sample and titrate against $N/100$ $Na_2S_2O_35H_2O$,
    using starch solution as indicator
    Starch plus iodine gives blue color.
    Slowly add $Na_2S_2O_3$ solution until blue disappears, done in cold solution
4   $2Na_2S_2O_3 + I_2 = 2NaI + Na_2S_4O_6$ This reaction is one of the most sensitive
    used in analytical chemistry   If no blue coloration results on adding the starch
    indicator solution, then the oxygen content of the sample is zero.
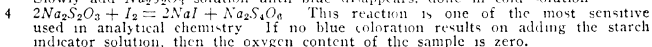
DEAERATION OF WATER

The removal of dissolved gases from water involves the doing of little
or no work in any thermodynamic sense, and therefore the introduction of
deaeration apparatus should not in any way diminish the overall efficiency
of a steam power system   Theory and practice make it clear that for the
complete removal of air in commercial feed water heaters and analogous
apparatus, the following conditions are required

1.—Exposure of the water in thin sheets or small drops to an atmosphere
   of which at least the portion in immediate proximity to the water under-
   going the final deaerating stage contains no appreciable partial pressure
   due to the gases which it is desired to remove

2.—Agitation of the water so that all parts are brought repeatedly to the
   liberating surface.

3.—Evaporation of some of the water or passing steam through or over it
   and continuously removing enough water vapor to sweep away the
   gases as fast as liberated, so that an appreciable partial pressure due to
   gases cannot build up.

The extent to which oxygen can be expelled by heating water in
standard open heaters at atmospheric pressure is shown in Fig. 5.   The
oxygen content is reduced as the boiling point is approached.   The problem
of heating water to the full temperature of the steam in an open heater

TEMPERATURES FOR ATMOSPHERIC PRESSURE, °F

5.   OXYGEN CONTENT OF WATER FROM STANDARD
                    OPEN HEATERS
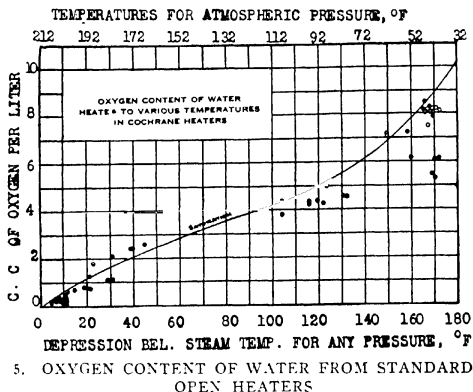
resolves itself into that of keeping the steam space, or at least the portion thereof adjacent the liberating surface of the water in the final stage of the deaerating operation, free of non-condensable gases. Similarly, in order to secure deaeration, means must be provided for maintaining a pressure equal to the pressure of water vapor at the temperature to which the water is heated, that is, the concentration of non-condensable gases in the heater must be avoided by suitably and continuously withdrawing the liberated air. A deaerating heater specially designed for the purpose gives zero oxygen under most practical operating conditions   If it is to be operated at a temperature above 212° F, that is, with a pressure above atmosphere, copious venting without waste of heat can be provided by the use of a vent condenser, which is a small closed heater through which the cold water is passed into the deaerator   The drips can be led back to the deaerating heater, while the air and other non-condensable gases escape through a thermostatically or manually controlled valve   If temperatures below atmospheric boiling points are to be used at times, an air pump is usually provided in the form of a steam jet exhauster connected to the vent opening of the vent condenser and followed by a gleaner heater for recovering the steam used by the exhauster   With this arrangement the pressure and temperature can be allowed to rise and fall in the heater and may reach wide extremes, as from a good vacuum to 30 or 60 lb back pressure, and at the same time no steam will be wasted and the water will be deaerated.

    In the open deaerating heater the water is heated to the full temperature obtainable with the amount of exhaust available, without loss of temperature head   Engines or turbines suitable for running under vacuum can exhaust to the deaerating heater at a vacuum corresponding to the temperature to which the water is heated, while units not suitable for vacuum operation can exhaust at atmospheric pressure, the steam from the latter being let down in pressure through a flow valve   The use of the deaerating heater fits in well with heating of the water in stages, thereby enabling the practical steam cycle to approximate closely in efficiency to the ideal reversible cycle   A heater designed for deaerating purposes can be used at first to supply water free from oxygen at 212° F, or higher, and, later, as when economizers are installed or when there is less steam available or more water to be heated, this same apparatus will deliver oxygen-free water at a lower temperature. The interval between temperature of the steam supply and the temperature to which the water is heated can be utilized for the operation of a makeup evaporator, and the liquid to be heated and deaerated need not come into contact with the heating steam.

HEATING BY EXHAUST STEAM

    Great economies are realized where the surplus of exhaust steam above that required for heating the boiler feed water can be applied to heating buildings or drying materials. A good oil separator should be installed to purify the steam of oil so that the returns, or condensate, can be brought back to the heater and used over again as boiler feed. The open heater then serves as a receiver or return tank for the condensate, at the same time automatically admitting the amount of raw water required to make up the total boiler feed supply. The oil separator can be attached to and form a part of the heater.

One lb. of steam used first in an engine or turbine and then in a heating system will replace about 1½ lb of steam required where the engine or turbine is run condensing and live steam is used in the heating system. If it is necessary to decide between running non-condensing the year around, using exhaust steam for heating, and running condensing the year around, using live steam for heating, the relative sizes of the heating and power loads and the length of the heating season should be considered.

Obviously in many cases, and especially where the power load is large in comparison with the heating load, the best arrangement will be a combined system We may note several classes of plants

1. Where all of the exhaust of the engine or turbine can be utilized for heating during the heating season, it will pay to shut down the condenser.

If only part of the exhaust is needed for heating, say less than one-half, the following courses are open

2. If there are two or more engines or turbines, one or more can be run condensing, and the others can exhaust into the heating system during the heating season.

3. An engine and turbine or two turbines can be arranged in series, part of the exhaust from the first being applied to heating and the remainder expanded through the second to the condenser.

4. If compound engines are installed, as they should be for running condensing, steam can be withdrawn for heating from the intermediate receiver of the engine

5. A bleeder or extraction turbine can be installed, that is, steam can be withdrawn from an intermediate stage of a condensing turbine for use, together with the exhaust from auxiliaries, in the feed water heater and in the heating and drying system.

6. Sufficient load can be carried on a steam-turbine-driven induction generator to supply steam for heating, the remainder of the power required being taken from the street circuit. The steam supply to the turbine may be controlled automatically by the pressure or temperature in the feed-water heater

The first and most important use for the exhaust steam is to heat the feed water, since all of the heat of the exhaust steam so utilized is returned undiminished to the boilers.

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The Cochrane Corporation

maintains a large engineering staff especially to study and make recommendations regarding those matters which principally control waste and efficiency in the boiler room.

This service is offered freely to any owner, manager or operator of a steam plant who wishes to ascertain and improve the efficiency of his boiler room, particularly as it is affected by the methods of heating, deaerating, softening, filtering and metering water; by the measuring of steam; and by the profitable utilization and control of low pressure steam, including the general problem of heat balancing.

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(See following page for addresses.)

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HAVANA   LONDON

PARIS

COLD WATER INLET
VENT PIPE
TRAP DISCHARGE
EXHAUST INLET
OVERFLOW LINE
PUMP SUPPLY
WASTE
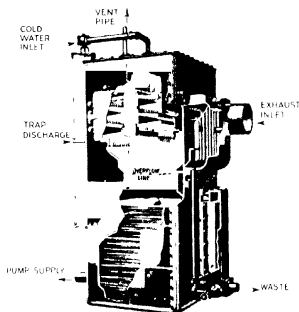
The Cochrane Open Feed
Water Heater

utilizes exhaust steam from boiler feed pumps and other auxiliaries to heat the boiler feed to steam temperature. One per cent. of fuel is saved for each 11° F. rise in temperature.

The Cochrane Heater serves as a hot well or return tank and as an automatic cold water regulator. Built in free-exhaust and back-pressure types. The horizontal cylindrical form is recommended for large capacities or where headroom is limited. Extra water storage capacity can be provided as required.

There are over sixteen millions of horse-power of Cochrane Heaters in service.

Ask for our Book 1340 on "The Profitable Utilization of Exhaust Steam"

The Cochrane Metering Heater

The recording apparatus produces circular charts with equal radial spacings for equal increments in rate of flow. The totals can be read from the automatic integrator forming part of the recorder. The accuracy is guaranteed to be within 1½ per cent. of actual weight, variations in the temperature of the water not exceeding 25° F. above or below the specified temperature.

This heater can be designed for use with engines exhausting freely to atmosphere, or can be of the Steam-Stack and Cut-out Valve type for use in connection with back-pressure exhaust steam heating or drying systems.

COCHRANE INDEPENDENT V-NOTCH METERS are used for measuring condensate, returns from heating systems, boiler blow-off, etc.

Ask for Bulletin 668
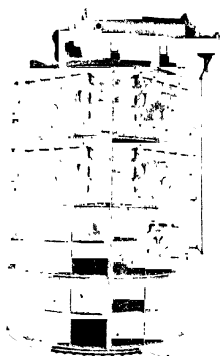
The Cochrane Deaerating Heater

expels oxygen and other gases from water and thereby prevents corrosion in piping, economizers and boilers. Can be operated at any pressure, as above or below atmosphere, and the water is delivered at the corresponding temperature. It uses steam extracted from a turbine or the exhaust of auxiliaries or live steam. The deaerating heater can serve as one of the stages of a regenerative feed heating system, or it can act as the condenser of a make-up water evaporator. It is an ideal condenser or heater for hot-water heating or service systems.

The Cochrane Deaerating Heater has solved the hot-water corrosion and "red water" problems.

Ask for Bulletin 672

The Cochrane Jet Heater

The Cochrane Jet Heater is peculiarly suited to large capacities, as above 200,000 lbs. of water to be heated per hour. It occupies small space, is low in weight, and for large sizes, is low in cost. It heats the water close to steam temperature and, due to a patented nozzle arrangement, is efficient over a wide range of loads. Can be supplied with barometric column or with storage tank and with the usual open heater accessories.

Ask for Catalog 1340

The Cochrane Closed Heater

The Cochrane closed heater has been carefully designed to secure a high rate of heat transfer, to facilitate access to heating surfaces and to eliminate expansion and contraction strains. Straight tubes are expanded at the water-box end into a substantial fixed tube sheet. The tubes are expanded at the opposite end into the tube plate of a floating head. Where four or more passes are used, the floating head may be in two parts to eliminate strains on the tubes and their fastenings. Effective steam circulation is insured by baffles, which also support the tube bundles. Either steel plate or cast iron shells are used, the latter being formed to hug the tube bundle closely.

Ask for Catalog 1340
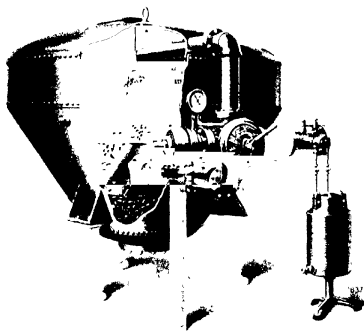
The Cochrane
Strainerless Conical Filter

is used for removing suspended matter and tur-
bidity from water in paper mills, textile estab-
lishments, laundries, swimming pools, and raw
water ice plants, for clarifying boiler feed water,
etc. It is built in single or multiple units, depend-
ing upon capacity, and is designed for 65 lb., 100
lb. or 125 lb. per sq. in. pressure. The conical
filter dispenses with distributing manifolds and
strainer valves, prevents passage of sand, and
insures efficient back washing. A single control
valve replaces the five separate valves usually
provided and makes operation practically fool
proof. Constant flow valves can be provided for
controlling rates of filtering and back washing.

A chemical feeder automatically proportions
alum or other coagulant. Water from Cochrane
Filters is sparklingly clear.

"Ask for Filter Book"
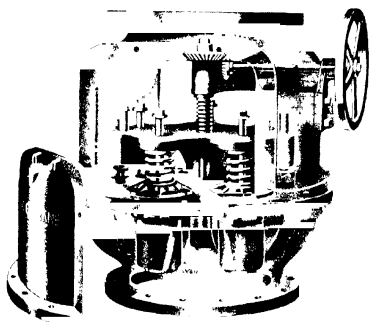
The Cochrane
Multiport Back-Pressure Valve

differs from the ordinary back-pressure valve in
that a number of small disks are used instead
of one large disk, thus reducing the size, weight
and travel of the disks.

Each disk has a separate dash pot and is held
to its seat by an independent spring, the tension
upon all the springs being adjusted simultane-
ously by a pressure plate, the motion of which
is limited so that a predetermined back pressure
cannot be exceeded. The position of the pres-
sure plate is controlled by a hand-wheel, or from
a distance by rods, chains, electric motor, etc.

The Cochrane Multiport Valve is built in all
sizes, for vertical, angle and horizontal pipes,
and with provision for water-sealing for vacuum
service. Multiport Valves are also built for use
as flow valves and as steam check valves.

Ask for Catalog 1381 on "Multiport Valves"
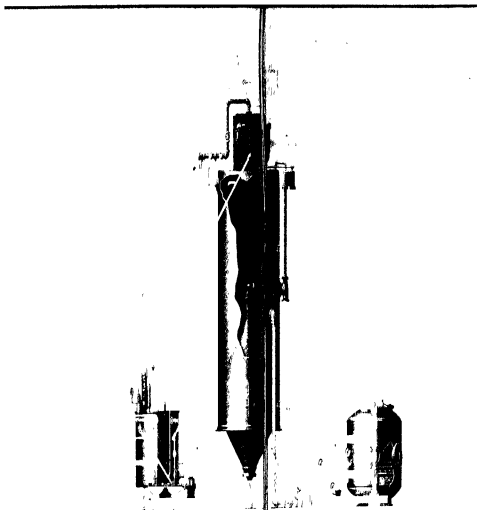
The Cochrane Hot Process Softener

In this apparatus the water is heated to 210° F. before the chemical reagents are added. The chemical reactions are much more rapid and complete in hot water than in cold water and the precipitates settle more rapidly.

The chemical feeding device is automatic, and feeds strictly in proportion to the amount of water treated. The chemical tank and proportioner are at ground level, and hoisting of reagents and climbing of stairs are avoided.

The apparatus combines the functions of feed water heater and softener and saves in cost and complication of piping. It can usually be installed in the boiler room, obviating expense for additional buildings and heavy foundations.

Complete protection to the boilers against corrosion and scale and the minimum amount of sludge-forming matter in the treated water are guaranteed. With the Cochrane Non-silite Filter the water is delivered crystal clear and there is no after-deposit in pumps, pipe lines or economizers.

Cold Process Lime Soda softeners are supplied where the softened water is to be used cold.

Ask for Bulletin 670, "Softening Water for Steam Boilers"
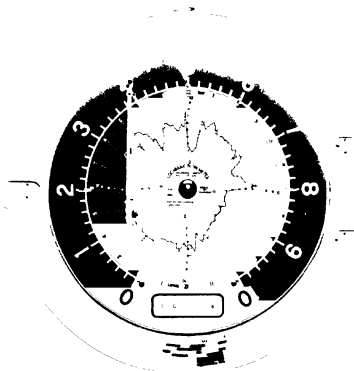
The Cochrane Flow Meter

is a simple, reliable and accurate device for measuring water, steam or air flowing through pipes. From the two sides of an orifice plate or nozzle clamped between flanges in the pipe line, pressures are led to the two chambers of a tilting U-tube, the angular displacement of which is directly proportional to the rate of flow.

The pressure connections are included in the orifice plate or nozzle, eliminating errors from faulty connections.

The movement of the U-tube is transmitted mechanically and directly to the pen and pointer arms. There are no working parts in the pressure chambers and no stuffing boxes. The chart divisions are uniform and can be integrated or averaged by using a standard radial planimeter. Pressure or temperature pens can be added, inscribing upon the same chart. The automatic integrator is positive in action and does not affect the deflecting member.

Ask for "Flow Meter Catalog"
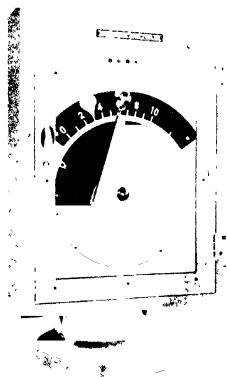
The Cochrane V-Notch Recorder

A complete instrument for indicating, recording and integrating the rate of flow over a V-notch or other form of weir. The indicating, recording and integrating members are driven directly from the float, without slack or back lash, and rapid movements of the float cause no trouble. The pen inscribes upon a chart having uniformly spaced graduations, while the pointer traverses a uniformly divided scale. All of the digits of the counting train, except unity, advance by whole numbers. The complete mechanism is supported by one casting and can be removed as a unit from the case, which is dust-proof. It is mounted on a pedestal, permitting of rapid set-up and of facing the recorder in any direction. The single clock drive may be either of a two spring type or an electric clock which does not require winding. Standard cams are available for standard Cochrane V-notches, but special cams will be cut to fit any form of weir of which the characteristics are known.

Ask for Bulletin 679

MANHOLE

MAIN AUX
DRAIN DRAINS

STEAM DRUM OF BOILER
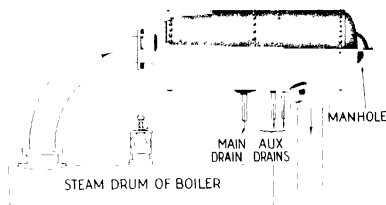
The Cochrane Steam Purifier

(Receiver Type)

is installed in the piping between the steam drum
and the superheater to protect the latter, and
also the turbine, against water and dissolved or
suspended solids brought over by priming or
foaming. It has large storage capacity and leaves
the entire volume of the boiler steam drum
available for steam and water storage and for
primary separation. It is strongly built and is
readily accessible. Its efficiency is not affected
by the quantity of water in the entering steam.

Ask for Bulletin 677

The Cochrane Steam Separator

stops slugs of water brought over from the boil-
ers, or due to condensation in the steam line,
and its cost is justified as insurance. It further
pays for itself yearly by arresting the moisture
which is always present in steam unless super-
heated, and sometimes even then, and which
moisture, if allowed to enter the engine, washes
away the cylinder oil, or in the case of turbines,
causes erosion of the blades.

Cochrane Receiver Separators store steam
close to the engine throttle, equalizing the flow
through the steam line and raising the average
pressure in the steam chest. It is thus possible
to use smaller piping and fittings, reducing first
cost and loss of heat by radiation. Cochrane
Receiver Separators have proved very effective
in eliminating vibration.

Ask for Bulletin 671
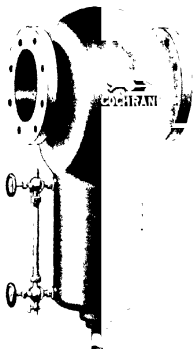
The Cochrane Oil Separator

Exhaust steam purified of oil by passing through a Cochrane Oil Separator is worth as much, pound for pound, as live steam at the same pressure for heating buildings, drying materials, heating water, cooking, operating low-pressure turbines, operating absorption ice machines, in drying or calendering rolls, etc.

The condensed returns will be free of oil and can be brought back and used over again for boiler feeding. Over 17,000,000 H. P. of steam boilers are being fed satisfactorily with water condensed from steam purified by Cochrane Oil Separators or heated by actual contact with such steam. Cochrane Separators are made in all sizes up to and including 96 in. and for vertical, horizontal and angle pipes.

Ask for our Bulletin on
" Steam and Oil Separators"
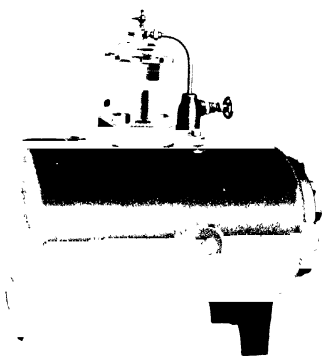
The Cochrane Discharger

is a pilot operated trap designed to handle large
quantities of water under the highest pressures,
as from steam purifiers. The pilot valve is oper-
ated by solid displacement bodies, while the
main valve is moved by steam pressure acting
upon a piston. The latter valve, which may be
of any size and capacity desired, opens full or
closes tight almost instantaneously and without
wire drawing. Both valves are accessible with-
out breaking gasketted joints. The trap bodies
are made of cast iron or of forged steel, accord-
ing to the pressure.

Ask for Publication 1601
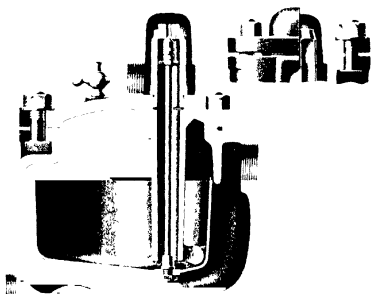
The Cochrane High-Pressure Trap

is used for pressures up to 250 lb. gage. A tilting bucket controls a valve which is made from a special corrosion and erosion resisting metal, as is also the valve seat. Valve and valve seat are removable after taking off the valve bonnet. The discharge passages are free and open, developing the maximum discharge capacity. The bucket and other working parts are attached to and removable with the cover. The single, packed joint is held by slip bolts and takes a circular gasket. The casing is approximately spherical in shape, giving the greatest strength and providing a large volume in the zone of action of the bucket.

Ask for Bulletin 667
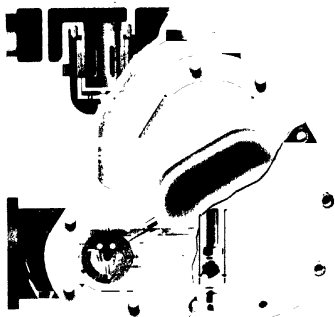
The Cochrane Multiport Drainer

removes condensate or drips from heating or
drying coils, radiators, jackets, low-pressure
steam and oil separators, etc. The hollow cylin-
drical valve is absolutely balanced and has large
ports, hence large capacity with low operating
pressure. It never leaves its seat, is self-cleaning
and is always water-sealed. The complication
of pilot valves is avoided. Upon taking off the
cover, the float and attached valve can at once
be lifted out. The valve seat is also easily re-
movable. There are no stuffing boxes, packings,
springs or links.

The top inlet prevents air binding. A hand-
tripping device is provided for moving the valve
or holding it open.

Bulletin 667 on Request
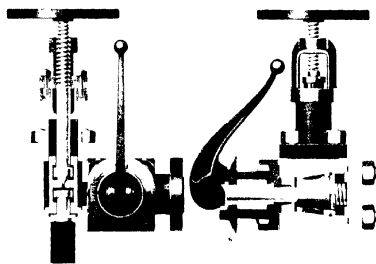
Cochrane Forged-Steel
Tandem Blow-Off Valve

This improved valve has been designed to
meet the exacting requirements of high boiler
pressures. Two valves in tandem are incorpo-
rated in a single, forged steel body. One of the
valves, of the rotating gate type is always opened
first and closed last. The operating lever is so
locked that before it can be turned the valve
member must be lifted from its seat, thus avoid-
ing scoring and abrasion. The main blow-down
valve in itself also embodies the double tightness
principle, that is, a by-pass valve equalizes the
pressure on the sealing disk, which is moved
from its seat before opening a check disk, which
takes all the wear of opening and closing under
pressure and flow. The sealing disk and seat are
not subjected to wire drawing, cutting or abra-
sion. Both sealing valve and check valve and
their seats are made of stainless steel, hardened
and ground, as is also the rotary gate valve.

Ask for Publication 1524